REPORT RESUMES

ED 014 731 CG 000 140

THE NATURE AND NURTURE OF INTELLIGENCE. LOUISVILLE TWIN STUDY, RESEARCH REPORT NUMBER 20.

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PUB DATE NOV 66

EDRS PRICE MF-$0.50 HC-$2.64 64P.

DESCRIPTORS- *INTELLIGENCE FACTORS, *HEREDITY, *ENVIRONMENTAL INFLUENCES, GENETICS, BEHAVIOR, FAMILY INFLUENCE, SPEECHES, INTELLIGENCE QUOTIENT,

INTELLIGENCE IS COMPOSED OF SIX INDEPENDENT ABILITIES--NUMERICAL, SPATIAL, REASONING, TWO VERBAL ABILITIES (VOCABULARY SIZE AND WORK FLUENCY), AND MEMORY. THE INDEPENDENCE OF THESE ABILITIES ARE EXPLORED BY RESEARCH STUDIES WHICH ARE DISCUSSED IN SIX CRITERIA CATEGORIES--(1) DIFFERENTIAL PREDICTION OF SUCCESS, (2) FACTOR STABILITY ACROSS AGE RANGES, (3) CROSS-CULTURAL GENERALITY OF ABILITY PATTERNS, (4) STABILITY OVER ABILITY LEVELS, (5) DIFFERENTIAL EFFECTS OF MENTAL ILLNESS OR BRAIN DAMAGE, AND (6) DIFFERENT RATES OF DEVELOPMENT. EVIDENCE OF THE HEREDITARY COMPONENT OF INTELLIGENCE IS PRESENTED IN TERMS OF RESULTS OBTAINED FROM TWIN STUDIES. STUDIES OF INBREEDING ALSO PROVIDE DATA. THE ENVIRONMENTAL COMPONENT IS ALSO DISCUSSED. IN VIEW OF THE RESEARCH, CO-TWIN CONTROL STUDIES DESIGNED TO STUDY THE EFFECTS OF STIMULATION OF ENVIRONMENT APPEAR TO BE NEEDED. (SK)

ED014731

LOUISVILLE TWIN STUDY

RESEARCH REPORT

FROM THE

LOUISVILLE TWIN STUDY

CHILD DEVELOPMENT UNIT

DEPARTMENT OF PEDIATRICS

UNIVERSITY OF LOUISVILLE

The Nature and Nurture of Intelligence

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Report No. 20

November 1966

UNIVERSITY OF LOUISVILLE · 1798 ·

The Nature and Nurture of Intelligence*

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* This paper was prepared for presentation to a Conference on Genetics and Biology: Genetics and Behavior, sponsored by the Russell Sage Foundation, Rockefeller University and Social Science Research Council Committee on Genetics and Behavior, November 18-19, 1966. The research reported here was supported by grants HD 00843 and K3-MH-18,382 of the National Institutes of Health.

I was very pleased to be asked to speak before such an illustrious audience. I am impressed with the opportunity it affords of attracting talent to a very exciting growing edge in an area which impinges on many sciences and which demands, perhaps more than any other, the interdisciplinary approach. I have been an American psychologist too long to invoke the excuse of being a newcomer, but you may wish to keep in mind that I was originally trained to be a Dutch lawyer.

I was preparing myself to present a review of some evidence for the fact that genes control part of the variance observed for scores on tests of intelligence and personality. Two reasons made me decide not to do so, but to broaden my presentation this morning to include an overview of some of the many problems which will need to be solved before we have a reasonably coherent theory of how the genes which produce the embryo also set the limits for subsequent behavior in the child and adult. Where possible I will indicate how some of these problems have been approached, and venture a guess how far we have moved. As a generalist by inclination, I have resisted for a long time the specialization required for a concentrated attack on a single problem, and this will handicap my presentation of evidence considerably.

The first reason for my decision not to limit my paper to a review of the evidence for genetic determination is that Professor Curt Stern reviewed the present state of the evidence in an incomparable manner at the recent IIIrd International Congress of Human Genetics (Stern 1966). The second one is that I have attempted to review parts of the evidence, mostly based on twin studies, in three recent papers covering different grounds each time (Vandenberg 1966a, 1966b, 1966c), and I did not want to repeat myself, nor am I ready to integrate all of it into one paper. In the published version of this paper I will be able to present somewhat more of this type of evidence than I can discuss here. Several of the questions which I will mention are regarded by many psychologists to be dead issues. They are not dead, but some of them smell as if they may be dying from neglect.

This morning I would rather address myself to the broad topic "The nature and nurture of intelligence". I will use the words nature and nurture in their original meanings, as you will see.

The Nature of Intelligence

What then is the nature of intelligence? Although the term is fairly old, it referred in past centuries to a generic difference between man and animals, or between animals and plants, and was not used as a graduated concept. The adoption of the same term early in the 20th century as an explanatory concept for individual differences in performance has hindered us ever since. Although others than Binet had tried to devise methods of distinguishing the performance of retarded children from that of normals, the first successful scale was devised by Binet and Simon (1905). It was of momentous consequence that Binet, early in his studies, relinquished the hope to base his work on a definition of intelligence. Instead, he proceeded in a purely empirical way to find tasks which could be performed by a majority of normal children of a given age. The adoption of age as the single criterion led, of necessity, to a heterogeneous collection of items, although some common threads such as vocabulary ran through the scale for all ages.

The almost astonishing success of the method and its rapid adoption in most of the Western world had some unfortunate consequences. It led quite early to a split between experimental psychologists who were bothered by the lack of theory, and those who used the method. The latter were the early clinicians as well as many persons in education.

Experimental psychology developed, for a time, an overriding interest in learning theory and disregarded, in general, the measurement of past learning embodied in abilities and individual differences. There were notable exceptions. Some statistically inclined psychologists began to study the intercorrelations between different tests, or between items of a test and developed a whole new branch of psychology. One of their accomplishments was the invention of factor analysis, a simplified way of solving a characteristic equation based on correlations between test scores. Unfortunately, by the time they obtained some results they did not affect too much the, by then, rather well-established traditions of applied testing which continued to measure a general IQ, or which attempted to predict rather general criteria such as success in college, or some type of abnormal behavior.

The studies of these statistically minded psychologists, of whom Thurstone and Guilford may be mentioned as the most prominent, made it quite clear that intelligence is of a multifacetted character which can hardly be expected to fit into one definition. It also became rather clear that the nature of the "general" intelligence measured by a given IQ test depends on the particular mix of item contents and can be expected to show considerable differences between babies, children, and average or talented adults. Instead of general intelligence, we may need to measure a number of different abilities, depending on what we wish to diagnose or predict. How many independent abilities there are and how useful for practical purposes each of them is remains unknown at this time. Thurstone put most of his faith in six, while Guilford (1959) has proposed that there may be as many as 120 abilities, which he has classified according to three basic characteristics: operations, contents and products, resulting in his well-known intellectual cube, rather than the squares we were more familiar with from other studies. (I go more for circles and spheres).

One problem with Guilford's studies is that until recently they were all based on adults with considerably more than average ability, where one can expect a highly differentiated structure of the intellect. Recently students of Guilford, such as Dingman, Meyers, Merrifield and Sister McCartin, have studied the applicability of his theories at the primary and secondary school level.

At Least 6 Separate Abilities

The available evidence, some of which we will review briefly further along, suggests that the independence of at least 6 abilities at all levels is well-established. These are: numerical, spatial, reasoning, two verbal abilities and memory.

There are two verbal abilities: the first one, vocabulary size, depends on the more or less passive recognition of meaning of words and is usually measured by multiple choice vocabulary tests, although individually administered tests such as the Binet and Wechsler call for a definition or explanation of words. The second verbal ability is called word fluency and deals with the more active recall of words to fit a given demand. These two verbal abilities appear to be independent.

The development of vocabulary, both active and passive, has been extensively studied and some of the tests have benefited from this. The importance of these two verbal abilities seems obvious. Many older tests of general intelligence were mainly made up of items measuring these abilities, and they still form an important part of newer tests, and correlate highly with the total score in Binet and Wechsler.

Besides their obvious face validity, the predictive validity of verbal tests for success in school or in many jobs is well-established.

Numerical or number ability, as it is usually called, is simply facility in basic arithmetic. It is generally measured by seeing how many problems can be correctly solved in a given time limit. The problems may or may not be purely arithmetical or they may be clothed in verbal garb, such as the classic problem about two carpenters building a house in 12 days. In an extreme form of the problem the question is: "How many carpenters would it take to build the house in one hour?" The improbable answer is 192. In addition, problems may be increasing in difficulty or be of roughly equal difficulty. While such differences tend to lower correlations between tests, all varieties seem to measure the same "general" number ability.

The development of number ability has not received as much attention as has the development of vocabulary or grammar. Piaget has not dealt with the acquisition of specific arithmetic routines, but rather with the development of over-all concepts such as "more" or "less" which may be necessary for understanding, but not for rote memorization of the table of multiplication, or of additions. It would be interesting to study whether the development of number ability in the preschool child can be distinguished from the acquisition of the vocabulary for different numbers and whether the learning of additions such as $1 + 1 = 2$ $1 + 2 = 3$ is not also rather like the learning of new words. If this is the case, number ability would not appear as a statistically independent factor in analysis of correlations of tests, until it had become well-routinized in an important number of the children studied. The validity of number ability or quantitative tests is well-established. Number ability is, of course, no predictor of success in mathematics, unless it were in numerical analysis.

Spatial ability, or ability to visualize spatial relations, may be for two dimensional patterns, or for three dimensional ones. The two are perhaps partly independent. While the existence of this ability has been known for a long time, and tests of it are included in some well-known intelligence tests, there is little information about its development in children, and not too much about its value in predicting success in occupations which, on the face of it, would seem to require the ability to visualize spatial patterns, such as biochemistry, engineering or architecture.

Macfarlane Smith (1964) has recently reviewed the evidence and he concluded that, at least in England, tests of this ability were not used as much as they should. He believes that spatial tests may provide better measures of the ability to think abstractly or to form general concepts, than do verbal tests and may have special merit for selecting research workers in mathematics and the physical sciences. We do not know whether this ability can be acquired or increased by training with moving models and films.

Reasoning ability is definitely independent from number, spatial and the two verbal abilities. It is less certain whether a good measure of "general" reasoning ability can be developed or whether there is a whole group of reasoning abilities. Ideally, this ability should come closest to what older workers believed intelligence to be. Existing reasoning tests usually have a considerable verbal or spatial component, and these two types do not correlate too highly. Some of the reasoning tests developed by Thurstone and by Guilford show only low intercorrelations with verbal and spatial tests, but their usefulness for occupational selection has not been fully explored. Neither do we know whether such an ability can be substantially improved by training in formal logic.

Memory is also definitely independent from the five abilities discussed so far, but may not be a unitary ability in the sense that the others are. Recent work suggests, first of all, that there are different mechanisms for short term and long term storage, as well as separate memory abilities for different types of material. In addition the measurement of memory does not test a capacity acquired in the past, but demands that the subject learn something during the test administration. Motivation to do so assumes thus a much more important role than it does in the measurement of the other abilities. In fact, some memory tests may be rather useful measures of the degree to which the subject, who is asked to take a number of tests, is cooperating and doing his best. I know nothing of the usefulness of memory tests for specific occupation, though I believe that some telephone companies used to employ a test of memory for digits in selecting telephone operators for long distance calls.'

Usefulness of Concept of Separate Abilities

The evidence for the basic nature of these abilities derives from factor analyses of batteries of tests, in which certain tests group themselves so as to suggest a common ability in each group. Therefore we have to review how useful the factors are which are found in factor analyses.

There are several ways to judge how useful the principal factors found in factor analytic studies are. We might use any of the following 6 criteria.

1. differential prediction of success in various curricula and jobs
2. stability of the factors over different age ranges
3. cross-cultural generality of the ability patterns
4. stability over different ability levels
5. differential effects of mental illness or brain damage
6. different rates of development

Review of evidence on these 6 criteria will have to be brief.

1. <u>Differential prediction of success in various curricula and jobs</u>.

There is not as much information on this as one might like, and what is there, is quite scattered in a variety of journals and books. Only a few representative studies will be mentioned here.

Thorndike & Hagan (1959) presented means on 5 different composite scores for 124 occupational groups. The composite scores were General Intellectual, Numerical Fluency, Visual Perception, Mechanical and Psychomotor Abilities. Some occupations showed profiles which seem characteristic for the nature of the work, for instance, architects were distinctly high on the Visual Perception tests, accountants and treasurers were high on Numerical and the highest composite score of carpenters was the Mechanical one.

Super & Crites (1962) summarize the record on differential prediction of different course grades in college for the PMA subtests and conclude that several studies found some correlations which make sense, but none of the correlations were higher than .50.

I have found several recent French studies. Bonnardel (1965a) compared 1,750 metallurgical workers and 300 office workers aged 20 to 30 years on a battery of 27 tests and found only modest correspondence between occupation and differential scores on these tests.

In another study Bonnardel (1965b) compared the performance on 27 tests of 1,030 men and 410 women grouped into 4 occupational classes. He found women superior on spelling, clerical speed and accuracy, and tests of manual dexterity, and men on verbal intelligence and concrete intelligence. This was true at all occupational levels, although there were minor differences. A comparison of factor structure for the data from both studies would be very informative about the comparability of such factor structures.

Nguyen-Xuan (1965) administered 4 verbal, 4 numerical and 4 spatial tests to 256 students from the classical and the modern sections of a French Lycee. Students in the classical section have more instruction in language and history, while the modern section has more mathematics and science. The correlations between tests and grades in mathematics, science, spelling, essay writing, in history and geography and in drawing were in part what one would expect: the verbal tests correlated most with the grade in essay writing, and the number of tests with the grade in mathematics. The spatial tests did not correlate with the grade in science, but gave the next highest correlation with the mathematics grade.

The total impression from reading several other studies seems to be that some differential prediction is possible, but success in school or job often seems as well-predicted by multiple regression or by general intelligence scores as by special ability. In part, this may be due to the fact that success often does require a combination of several abilities. At least one can say that the evidence is not entirely negative.

2. Stability, i.e. comparability of factors over different age ranges

There has been a good deal of research on this topic. It has often been in the context of a controversy whether there is increasing differentiation of abilities with age, or whether there is instead an increase in general ability and a lessened importance of specific abilities as the child becomes an adult.

Reinert, Baltes & Schmidt (1965) reviewed 36 studies dealing with the question whether during childhood and adolescence more and more independent abilities emerge as was suggested by Burt (1919). Only 15 of the 36 studies analyzed supported this theory, but these 15 studies were, in general, methodologically superior to the one with negative results. They point out that in most studies age differences are confounded with differences in ability.

In (1958) Wewetzer proposed a divergence hypothesis which stated that the factorial structure of subjects with higher ability would be more differentiated than for subjects with lower ability.

Burt (1919) and Garrett (1946) had earlier proposed a differentiation hypothesis which proposed that the factorial structure of older Ss would be more differentiated than for younger Ss.

Lienert (1960, 1961) combined the two hypotheses into one which he called the developmental divergence hypothesis: the factor structure for children with greater ability should resemble that for older children, and the factor structure of less gifted children should resemble that of younger children.

Reinert, Baltes and Schmidt (1965) proposed calling this model the performance differentiation hypothesis. According to this model the degree of differentiation of a factorial structure of intelligence is dependent on the level of the intellectual test performance. But performance is a function of age and ability combined. (Lower ability can, to some extent, be compensated by higher age and vice versa). They performed two related studies to test the new model for the differentiation of intelligence into different abilities. In the first study two groups of boys aged 10-1/2 versus 12-1/2 were contrasted. These two groups were selected to have relatively equal intellectual levels by making up groups which had mean IQ's of 106 versus 94. In the second study two groups of boys of equal mean IQ (99 versus 100), but of a different mean age and therefore a different level of mean intellectual test performance, were compared.

In the first study the same factor structure was predicted, in the second study they predicted a more differentiated factor structure for the group with the higher test performance. The results supported their predictions. In a later study by Reinert (1965) of girls, only the first prediction was confirmed but not the second. This raises an interesting question about sex difference in development of mental ability which might necessitate controlling sex differences. Many older studies used unequal numbers of male and female subjects.

Another difficulty when trying to put findings for the earlier studies together is that all used different sets of tests. In some studies one could hardly expect results different from the reported ones, either because there was too large a variety of tests, or not enough of it. In many studies the results from one group with one set of tests were compared with the results obtained in another study (often by another investigator) with another set of tests.

There are only a few studies in which the same or highly similar tests were used with subjects of different age ranges. Besides the early studies of Kelley (1928) and the Thurstones (195_) there have been several reports by Meyers, Dingman and their associates on their efforts to check the comparability of factor structures in normal children at ages 2, 4 and 6 and retarded children of comparable mental ages. In general they were able to demonstrate a high congruence across the two samples at all 3 age levels. (Meyers, et al 1962, 1964).

3. Crosscultural generality of factors

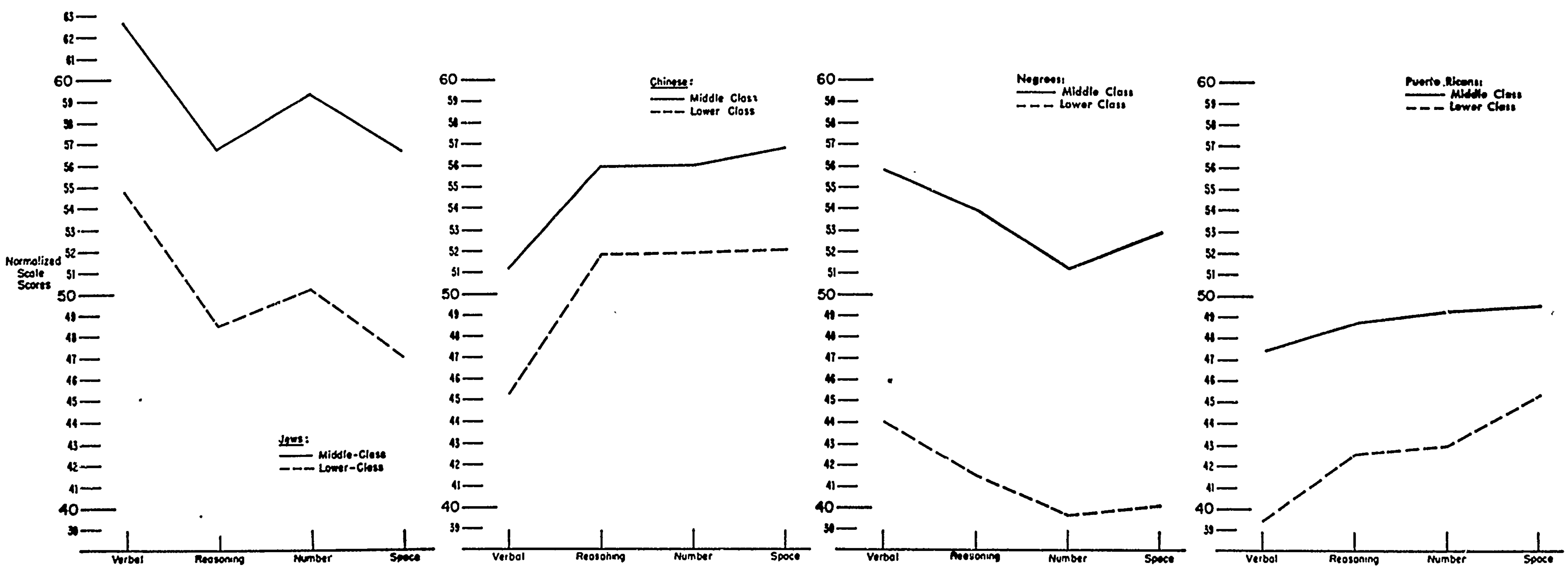
There have been only a few direct tests of crosscultural generality, although a variety of factor analytic studies have been performed in many countries. These do, in general, arrive at a number of independent factors, which seem rather similar from one study to the next. Vandenberg (1959) administered to Chinese students 20 tests from the battery used by Thurstone with University of Chicago students and found a high congruence between the two sets of data for the spatial, verbal, numerical, memory and perceptual speed factors. The values for the congruence indices ranged from .910 to .730. The only relationship with measures of acculturation was for the verbal factor.

In a second study, Vandenberg (1965) administered the same battery to South American students and compared the factors from their results with those from the Chinese students. Congruence indices between .953 and .780 were found for 1. a native language factor, 2. a verbal ability factor, 3. a memory factor, 4. a spatial visualization factor, 5. a perceptual speed factor, 6. a number ability factor and 7. a poorly defined reasoning factor.

There is some less direct evidence on crosscultural generality of ability factors in a recent monograph by Lesser et al. (1965). Verbal ability, reasoning, number facility and space conceptualization were studied in middle and lower class families of 4 cultural groups: Chinese, Jewish, Negro and Puerto Rican, with 20 boys and 20 girls in each group. The results are shown in Figure 1. Interesting

Figure 1

Comparison of Test Performance of Children from Middle and Lower Class for 4 Different Cultural Groups (after Lesser et al. 1965)



differences may be noted between the 4 groups in the difference between middle and lower class performance and different patterns of abilities between the 4 culture groups. What is of importance in our present context is, however, that in each culture the 4 separate abilities followed similar patterns in the two socioeconomic groups.

Vernon (1965) administered a battery of verbal, memory, perceptual and performance tests, as well as items based on Piaget's studies of the development of concepts to a group of English and a group of West Indian boys. He reports finding rather similar factor structures in the two groups. Because the factor loadings are not reported for the West Indian group, it was not possible to calculate indices of congruence at this time, but such may be possible later.

We have earlier discussed the controversy between increasing and decreasing differentiation. Another topic which could have been introduced then, which complicates interpretation of the relevant studies, must be mentioned here. Many advocates of differentiation probably believe in distinct abilities, and may even believe that they are normative. They still can be due to environment (common training) or heredity (innate capacities).

There exists another view which has not been forcefully proposed for several years. It has been expressed by Thomson (1951), Ferguson (1954) and perhaps less wholeheartedly by Vernon (1956). According to these views abilities and patterns of abilities (or factors) result from over-learned acquisitions. The accumulation of skills, facts, etc. that goes on may resemble specific abilities because learning is somewhat segmented into specific subject matter. Bonds are formed between temporal neighbors among items that are learned equally well or poor due to factors of motivation and so on. If this view is correct, then one would not expect the cross-cultural generality of ability factors referred to above.

Bonnardel (1965c) compared the performance on 31 tests of 3 age groups, 17-18, 20-30 and 30-40 years of age. He only compared means and quartiles, but his data would provide a valuable test of the comparability across ages of a factor structure.

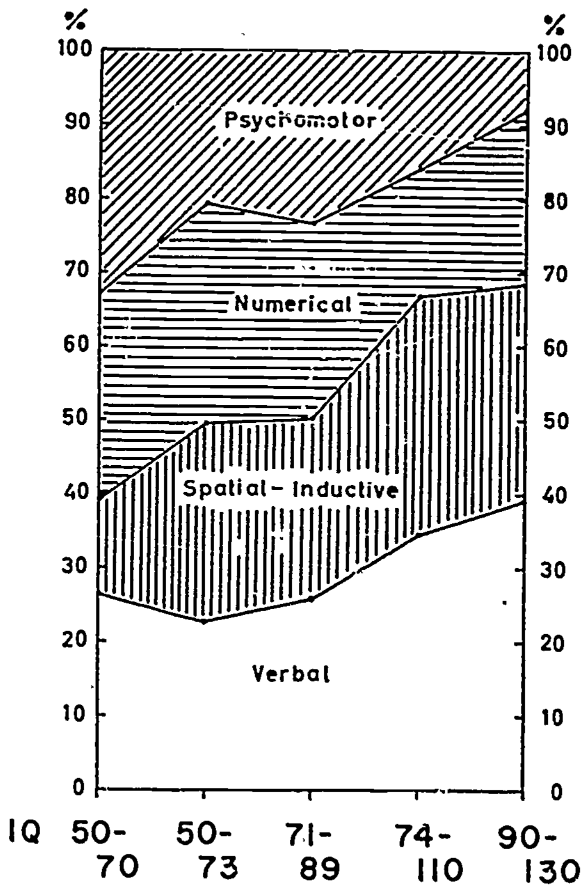
4. <u>Comparability of factors between different levels of ability</u>

As pointed out by Reinert (1965) one can, to some degree, trade ability level for age and expect rather similar results. What happens to the structure of abilities when one considers not merely low average ability, but actual mental deficiency? That there is still a good deal of differentiation of abilities is the conclusion of the studies by Meyers, Dingman and associates mentioned earlier in connection with comparability across age levels.

Similar conclusions were reached by Kebbon (1965) in his monograph on a series of studies on the structure of abilities in retardates in Sweden. Using batteries of 11, 16 and 25 tests with retardates 15 to 65, 15 to 60, or 20 to 34 years old and comparing their results with those of a group of 92 normals, he obtained highly similar factor structures. Congruence indices ranged from .95 to .97 for 4 factors, although part of the time a fifth factor was present which was harder to interpret. The spatial factor was largely one of shape reproduction rather than one of mentally manipulating a pattern in 2 or 3 dimensional space.

The different factors accounted for different proportions of variance for the ability groupings as shown in Figure 2. I want to make one comment about this figure and call your attention to the fact that the psychomotor factor, i.e. the speed of movement accounts for more variance and appears to play a much more substantial role in the test performance of retardates, confirming the general impression that they are slow.

Figure 2



PER CENT OF COMMON VARIANCE ACCOUNTED FOR BY FOUR FACTORS IN FIVE DIFFERENT IQ GROUPS

(Kebbon 1965)

5. Is there any indication whether the different abilities are differentially affected by mental illness or brain damage?

Such information would give support to the idea that the abilities were not only behaviorally distinct but even functionally separate. I have not had time to look for evidence of differential impairment of primary mental abilities in various types of psychoses and neuroses, but it is my impression that one would not find many studies. This is due to the fact that tests of the specific abilities isolated in factor analyses generally have not been used in studies of psychotics or neurotics. Instead a variety of "clinical" tests have been used whose exact nature is not understood fully since they often have been used very little with normals, so that little is known about their psychometric properties. The distinction between concrete and abstract ability has played a large role in this research. Even such a well-known tool as the intelligence test of Wechsler has never been administered in a battery which included tests selected as marker variables of well-defined ability factors, so that its subtests cannot be specified precisely in terms of the primary abilities agreed upon in studies of normals.

While little work has been done on isolating specific primary mental abilities which are differentially impaired by various types of functional forms of mental illness, the situation is different for brain damage.

As the ideas about the nature of basic mental functions changed, the ideas of relating basic functions to specific brain centers were bound to bounce back and forth. The purely philosophical notions of highly specific "ideas" or "faculties" led to the phrenologist notion of quite small areas of localization which might even show themselves as bumps on the head, if well-developed.

When intelligence was being regarded as more unitary in character, the idea of mass action of the brain came to the fore, including almost complete recovery of function after initial shock, except for general impairment due to loss of volume and supposing that no primary sensory area was touched.

For many years now the view has been proposed by factor analysts that intelligence is not a unitary ability, but one composed of a number of relatively independent abilities. During this same period there has been a return to the idea that specific areas of the brain are more important for certain abilities than for others.

There is no perfect correlation, but the two ways of thinking seem to occur in both areas of investigation, though perhaps somewhat out of phase at times. Present thinking seems to favor the idea of multiple functions, whether mental or neurological.

Localization of abilities

While the idea of detailed localization of ideas or of small isolated mental functions has long since been abandoned, work on the assessment of brain damage by Luria (1955), Halstead (1955), Reitan (1955), Russell (1948, 1959), Zangwill (1960) and many others suggests that damage to certain areas of the brain is more likely to result in impairment of some functions than of others. A thorough review of the psychological effects of brain damage was provided by Meyer in 1961, and briefly by Yates (1966).

Impairment of spatial perception seems to be a disproportionately important tool in the diagnosis of brain damage, whether the test used is the Bender "Gestalt" visual test, the Graham-Kendall memory for designs test, or the Gottschaldt hidden figures test. The area that is often especially implicated when spatial perception is impaired is the posterior part of the right parietal lobe, and/or the lateral part of the right occipital lobe. Verbal performance is often less affected in such cases. Less is known about the other abilities. There is impairment of articulate speech when an area near the third frontal convolution of the left cerebral hemisphere is damaged. Spelling and grammar may also be impaired in such cases. It is unfortunate that no measures of a number of distinctly different abilities were used in many of the studies.

While Luria (1965) holds that factor analytic investigations have helped little to reveal the basic dimensions of higher mental processes, he does believe that some functions can be distinguished by their selective impairment when certain areas in the brain are disturbed. He stresses the social origin and cortical basis of all higher mental functions in man. The social origin is really a consequence of the cortical control of nervous functioning which has reached its ultimate form in man due to evolution. The social learning is mediated by what the Russians call the second signaling system. This concept is not too different from Gross' (1902) and

Heymans' (1908) concept of secondary function; which stands for the predominant role of past experience versus the momentary sense impression in guiding a person's behavior. Gross and later Heymans thought of secondary function as one end of a bipolar personality dimension with primary function at the other extreme.

Luria mentions the following more or less distinct functions, although he warns that a focal lesion seldom results in the complete loss of a specific function: speech, verbal understanding, fine motor control as in writing, calculation and object naming. He makes the same basic distinction, as others do, between the left or dominant hemisphere and the right one, with the damage to the former more likely to result in poor word comprehension, writing disorder and impaired ability to recall words or name objects. When the visual area is damaged there may be lessening of visual perception, or spatial orientation, or of ability to calculate.

6. Comparison of developmental rates

Zubin (1960) has suggested another way of isolating basic dimensions of abilities, namely by studying to what extent different skills develop simultaneously or at different rates. Unfortunately we have hardly any information on this, at least not of the detailed kind necessary.

What will be necessary is a comparison in the same subjects of the development over time of several separate abilities, such as verbal comprehension or vocabulary contrasted with number ability, spatial ability, etc.

As mentioned before, the investigation of abilities has in general been little influenced by the study of learning and vice versa, while neither have had enough contact with the field of child development. Fortunately the situation is changing. There are many studies of learning being conducted with children, although it is still too early to expect summaries with many detailed replicated findings. Many of these studies are in progress in Russia, and some reports were given at the XVIIIth International Congress of Psychology.

I will only mention a few specific studies of learning. Stevenson and Odom (1965) studied the performance of 354 children in the fourth or sixth grade of five learning tasks: paired associates, concrete discrimination, abstract discrimination, concept formation and anagrams. The results indicated that different learning tasks require different abilities, and that some kind of learning are not related to the abilities measured by the California Test of Mental Maturity.

Several attempts have been made to relate learning to mental abilities in studies conducted at the Educational Testing Service. Allison (1960), Stake (1961), Games (1962) and Duncanson (1964) all found relationships between ability measures and the parameters of learning curves fitted to the performance of single subjects on individual tasks. Many of the relationships between learning tasks and ability measures dealt with material similar in content. Manley (1965) did a similar study concentrating on concept attainment tasks.

Newer ideas about intelligence

With the advent of electronic computing machines a field of study named artificial intelligence has developed. Have we learned anything relevant to our inquiry from these studies? Without going into much detail we can answer with a guarded, "Yes", I would say. Computer theories have made some contribution to our understanding in two ways: 1. there is first of all the demonstration how a solution to a problem once worked out in "subroutines", can then be used as a single instruction and one can thus think about a complex operation such as f.i. matrix inversion as a single step as easy as adding. This is a dramatic illustration of the way the mind works: it can use shorthand symbols for a very lengthy and varied task and thus condense a reviewing process enormously. We think: on the way home I will stop at Harry's or; when preparing that paper this particular point should be emphasized. By the way, subroutines are also a nice illustration of the power of cultural inheritance to multiply any given person's own capability.

The second way in which computers have helped our theoretical thinking is because they are vivid demonstrations of the fact that one and the same structure can accomodate an infinite number of states and processes through the variety of the programs stored in it and the data the programs are set to work on.

Information theory, so far, has had little impact on the measurement of ability, though two exceptions come to mind: the PSI apparatus of John & Miller (1957), an adaptation of which is being used by the Psychological Corporation, I believe, and the paper and pencil mazes of Elithorn (Davies & Davies 1965). In both of these an attempt is made to define the difficulty of a problem in terms of the amount of information, i.e. the number of choices to be considered. Their relation to conventional ability measures is not known.

One very important aspect of intelligent behavior has been seriously neglected. Social intelligence, or the ability to do the "right" thing in interpersonal situations has not received the same amount of attention as have other aspects of intelligence. One big problem is that it turns out to be rather difficult to define what is "right". Recently Guilford has added this area to his sphere of investigations.

After this lengthy attempt to convince you that intelligence is best regarded as a bundle of independent abilities, I will finally turn to my main topic which is:

<u>Are these abilities in part determined by genes?</u>

I am the family face;
Flesh perishes, I live on,
Projecting trait and trace
Through time to finis anon,
And leaping from place to place
Over oblivion.

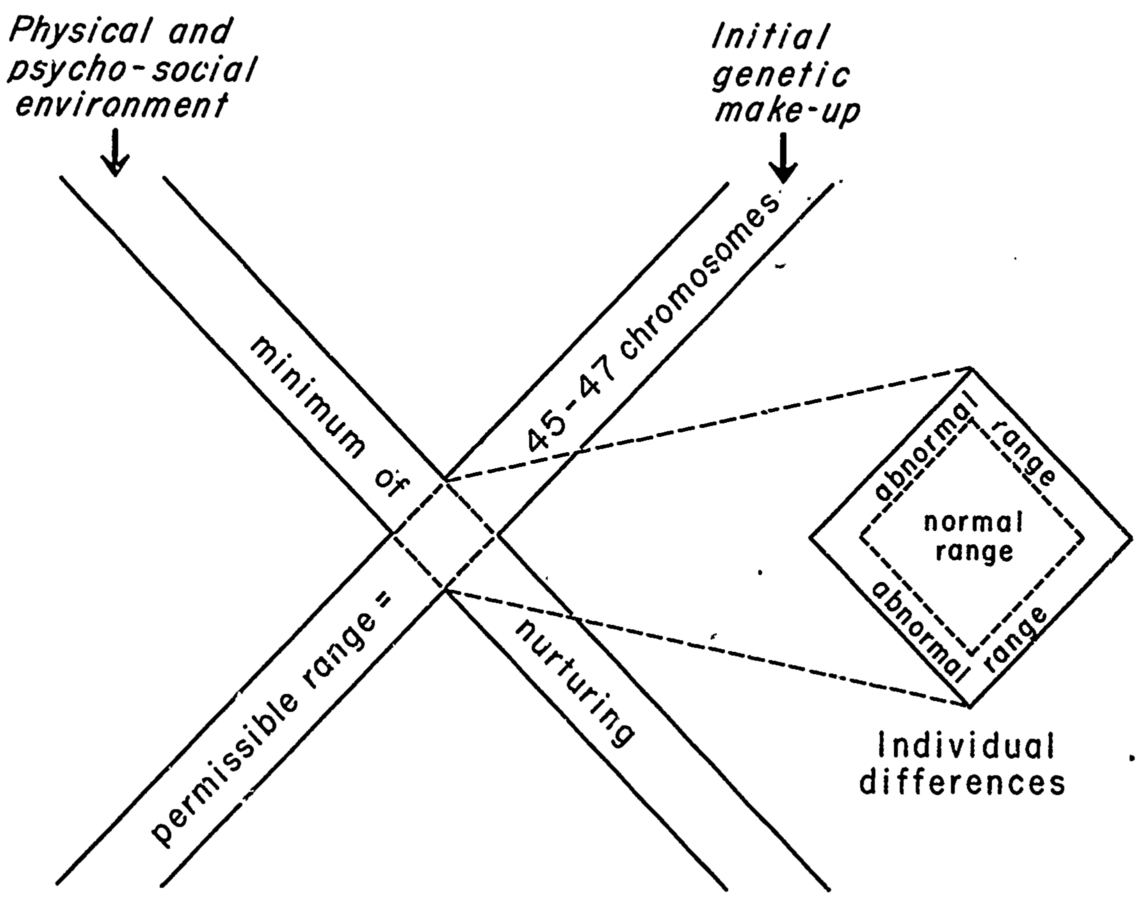
from Thomas Hardy's "Heredity"

Before we discuss hereditary factors in ability and personality, a few remarks are in order to get our perspective right. Differences between individuals are similar to the small part of the iceberg which shows above water. Behavior geneticists depend on individual differences for their livelihood. As a result they tend to overlook the enormous amount of common heredity which distinguishes man from dog or horse. It is amusing to speculate what we would be like if we had descended from cats as Day (1936) has done. Except for completely stunted individuals, this common heredity includes having fingers, toes, a heart and lungs, as well as the development of abilities such as recall (even in the absence of the original stimuli), foresight, conceptual thought, self-awareness beyond a level present in any other species and the display of <u>activities</u> which might variously be called "building", "rearranging", "tool-making", or in general: "modifying the environment". This common heredity can be found in any human culture, past or present, technically advanced or primitive.

Estimation of heredity-environment variance ratios take place in the narrow confines of the intersection of a normal environment and a normal genetic make-up. The normal environment includes the very unusual conditions found today on the surface of our earth, it includes a healthy uterus and a "normal" psychosocial environment, at least during part of childhood. To underline this point I have drawn Figure 3. The permissable variation in

Figure 3

Schematic representation of environmental and genetic limits imposed on "normal range" of individual variation



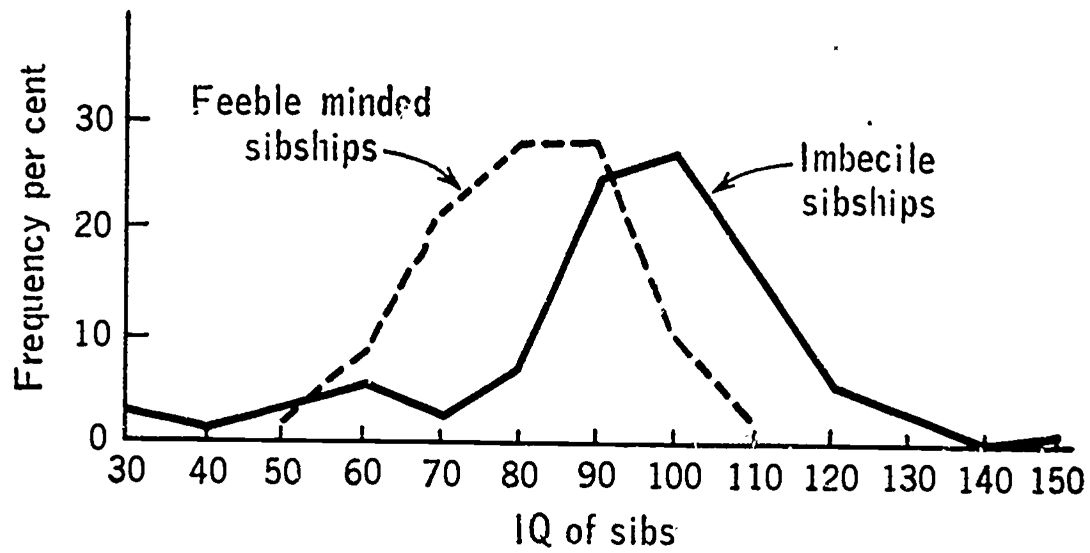
genetic make-up is just as small. A little extra genetic material or even a single mutated gene may be lethal or cause gross abnormality.

I will not review the story of phenylketonuria, of Down's syndrome, or of the sex chromosomal and other autosomal aneuploids, other than to mention that the psychological tests to be used in examining such cases need to be refined as much as possible if we are to learn the maximum amount from these unfortunate children. Information on such cases should then be collected for future reanalysis and perhaps eventually linkage studies.

It is quite possible that most cases of severe retardation are due to a variety of major genes, perhaps a single one in each given instance, while the higher grade retarded may be part of the normal distribution of intelligence which is controlled by polygenes. This is suggested by data from Roberts (1952). He plotted the distribution of IQ's of 562 sibs of high grade and low grade mental defectives. The mean IQ of the sibs of the low grades was about 20 points higher than that for the high grade group and rather similar to that for the general population. The results are shown in Figure 4.

Figure 4

Distributions of IQ for siblings of feeble-minded (---) and in imbecile (—) propositi



A study of Halperin (1945) shows that some mentally deficient parents have normal children, and that some of the mentally deficient are born to normal parents. Starting with mentally deficient children (admittedly an unrepresentative sample of the general population) all the children of the parents of the propositi and the parents themselves were classified. The results are shown below in Table 1.

Table 1

The percentage of average, inferior and mentally defective children born to various combinations of parents (The number of cases are shown in brackets)

		CHILDREN		
Parents	N	% Average or above	% Inferior IQ 70-85	% Defective IQ 50-70
Average x average	18	73 (13)	5 (1)	22 (4)
Average x inferior	59	64 (38)	33 (19)	3 (2)
Inferior x inferior	252	28 (70)	57 (144)	15 (38)
Inferior x defective	89	10 (9)	55 (49)	35 (31)
Defective x defective	141	4 (6)	39 (55)	57 (80)

Four other methods can give some information about this question: 1. Family studies, 2. studies of adopted children, 3. twin studies, and 4. studies of the effect of inbreeding. We do not yet have information by all these methods on specific abilities, and will occasionally fall back on general intelligence.

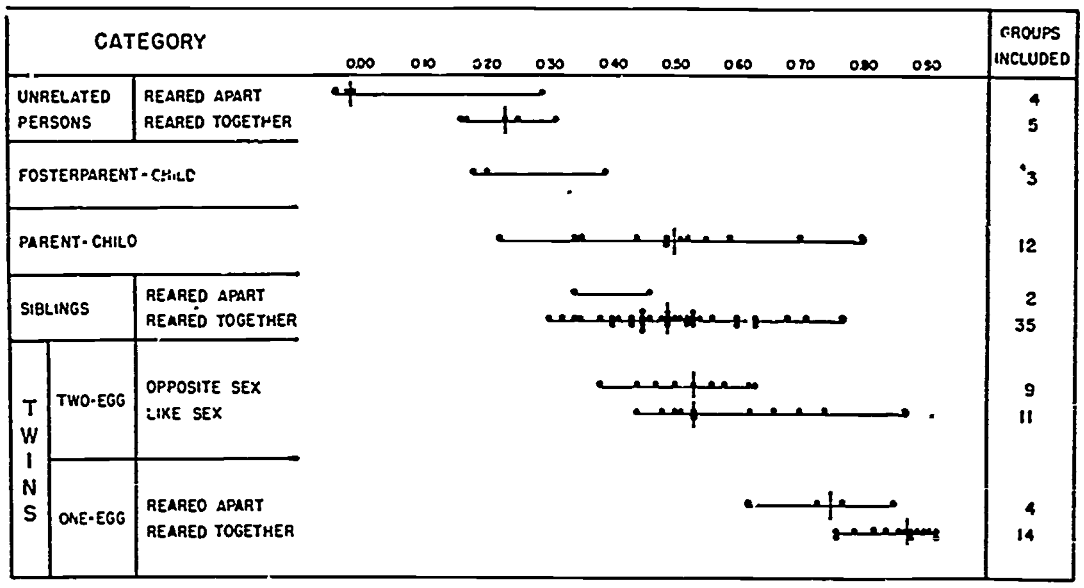
1. Family studies

As far as I know we have no information about correlations between relatives on specific ability scores. For general intelligence Erlenmeyer-Kimling & Jarvik (1963) have summarized evidence from 52 studies reporting on 99 correlations between paired individuals of varying degree of genetic relationship. The pairs ranged from unrelated through parent-child to identical twins The results are shown in Figure 5. The dots represent correlations from single studies, the lines show the range of values and the median is shown by a short vertical line. While noting that the regular increase in the size of the correlation is good evidence for the importance of heredity in ability, Vandenberg (1966a) has suggested that the variability of the values may be due to differences between the content of the tests which are related to the degree of genetic determination. We will return to this in the section on twin studies.

Figure 5

Distributions of correlation coefficients for scores on intelligence tests of paired individuals of various degrees of blood relationship

(from Erlenmeyer & Jarvik 1963)



2. <u>Studies of adopted children</u>

Because similarity between members of a family reflects both common genes and a common environment, one would like to place selected babies with an increased risk for schizophrenia or mental retardation in carefully selected foster homes. While such selection is generally not possible, we do have a limited amount of information on children placed in foster homes. Honzik (1957) has summarized results from the study of Skodak & Skeels (1949), and compared them with the results from the California guidance study. The data concern the resemblance of children to their foster parents and to their biological parents. Figure 6 summarizes the results. They show that the children resembled their biological parents much more than their foster parents, except for a brief period in the beginning, which may be due in part to the lack of predictive validity of baby tests. As a matter of fact, they resembled their biological parents just as much as did the California children who grew up with their own parents.

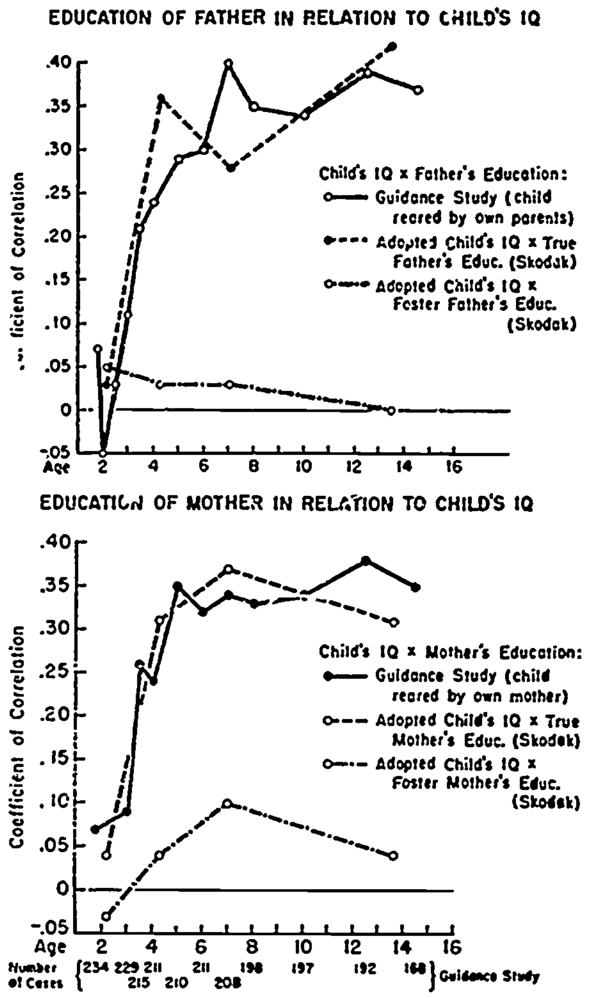
For a detailed description and evaluation of studies of the effect of placement in foster homes on children from retarded mothers, see Stoddard (1943). We will return to this topic briefly when we consider the nurturing of intelligence.

3. Studies of twins

In discussing the variability of results summarized by Erlenmeyer-Kimling & Jarvik, I suggested that different tests might have different heritabilities because they might be made up of different mixes of items measuring various abilities which might differ in the degree to which they are determined by genes. That

Figure 6

IQ RESEMBLANCE OF ADOPTED CHILD
TO FOSTER AND TRUE PARENTS (after Honzik, 1957)



there is indeed such a difference was the conclusion of a recent paper (Vandenberg 1966a). In addition, Nichols (1965) has shown that specific abilities may have higher heritabilities than general ability. His data came from twins taking the National Merit Scholarship Qualifying Test. It is of interest to note that even in these talented subjects there were such differential effects to be shown. On a test for English usage boys showed little effect of hereditary influence, but girls did. For boys the strongest evidence for heredity was in a test for mathematics usage.

Before discussing specific findings from twin studies, we will briefly review some criticisms of twin studies. They may be summarized as follows:

1. Unrepresentative of general population
2. Lack of objectivity in classifying twins as MZ or DZ
3. Environment not the same for MZ and DZ twins
4. Differences of uterine conditions for MZ and DZ twins.

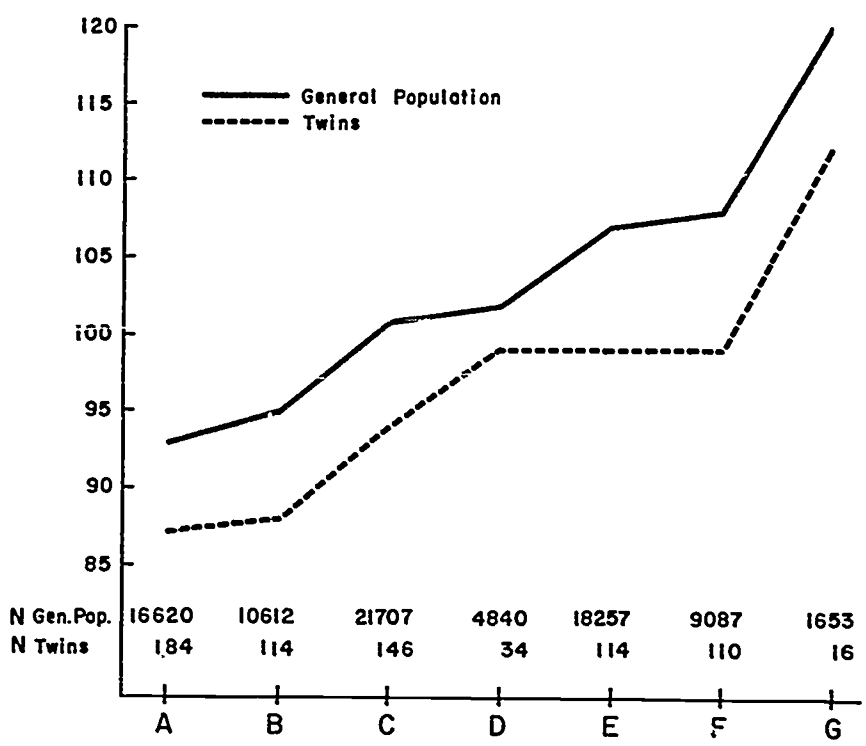
1. <u>Are twins different from the rest of the population from which they come?</u>

There are some pieces of information on this. Twins are often said to be slower in their language development, especially before they start school, but the studies were generally based on very small samples. Better data came from France (Zazzo 1960) and Sweden (Husen 1960). Soon we may have data from the U.S. when project TALENT analyses its twin data (Schoenfeldt 1966).

Figures 7 and 8 make clear that there is a consistent difference in favor of single born children. On the other hand there is the comforting thought that there are many twins among the National Merit Scholarship contenders and winners.

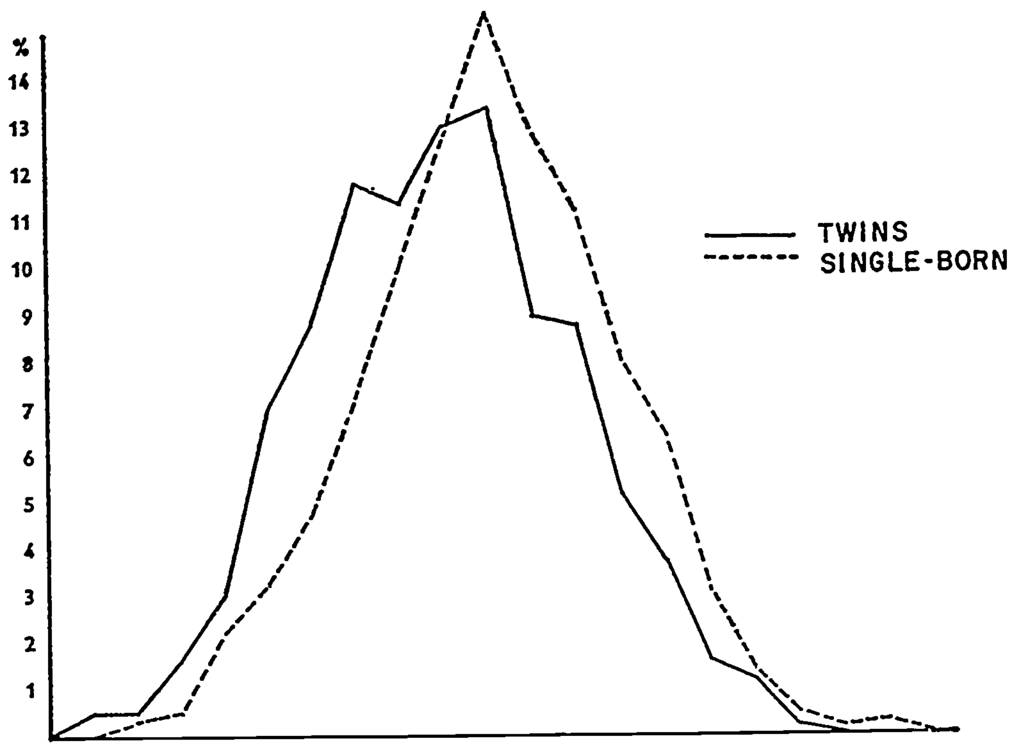
Figure 7

DISTRIBUTION OF IQ's, BY OCCUPATION OF FATHER, FOR TWINS AND SINGLETONS (ZAZZO 1960)



A. Farm workers
B. Workers in towns of less than 2000
C. Workers in larger towns and cities
D. Salaried employees in towns of less than 2000
E. Salaried employees in larger towns and cities
F. Managers and merchants
G. Professional men

Figure 8



DISTRIBUTION OF READING SCORES OF TWINS AND SINGLE CHILDREN (GIRLS)

(Husén 1960)

2. Are twins classified objectively into identical (MZ) and fraternal (DZ) types?

Most modern twin studies use extensive blood group tests which make misclassification of an MZ pair as DZ impossible, and miss the classification of truly DZ in only about 5% of the cases when the present serological tests fail to detect a difference. Use of fingerprints or anthropometric data generally does not add enough to warrant the added trouble, although single items such as a gross difference in height or in color of hair, iris or skin (f.i. on inside of the arm where it is usually covered) may occasionally help. For large scale twin studies it has been shown repeatedly that a few questions about the frequency of mistaken identity on the part of close friends or relatives will allow sufficiently accurate diagnosis within the limits of the accuracy of the variable under study, whether it be mental test scores or a physical illness with an uncertain claim to hereditary transmission. Of course, one should not ask twins whether they are identical or fraternal because there is an amazing amount of misinformation about this in the minds of twins and their parents.

3. Is the environment the same for MZ and DZ twins?

The question really should be whether the range of within-pair environmentally produced differences is the same for identical and fraternal twins? This is a very complicated matter which cannot be answered today. There are a few things which we can say, at least about the effect on intellectual level. First of all, we can resort to some sophistry which goes like this: The greater differences in parental treatment of fraternal twins compared to identical twins is undoubtedly due in great part to reactions to very early genetic differences and thus may be classified with heredity. But this argument will not satisfy purists, environmentalists or hard-headed experimental psychologists. Fortunately, we have a few very suggestive findings.

Nichols (1965) reported intraclass correlations (concordance) for MZ and DZ twins who had been exposed to different experiences and those who had not. The figures are remarkably close. Perhaps more convincing yet is the analysis by Vandenberg & Johnson (1966) of the IQ differences of identical twins who were raised apart. When the pairs, who were collected from the literature, were put in two groups on the basis of how soon after birth they were separated, greater within-pair differences were found, not for those separated early, but for the later separated pairs. While not too much should be made of this, at least it argues strongly against a systematic influence. When we discuss the affect of early stimulation we should remember this finding.

4. Lack of comparability of intrauterine environment

Price (1950) has made a convincing argument for the idea that the prenatal environment of fraternal twins is probably more nearly alike than it is for identical twins. The pair reported by Falkner (1962) certainly underlines this point in a most convincing fashion. Due to vascular anastamoses, one MZ twin had pumped blood into the other, resulting in marked differences at birth, which only slowly disappeared.

Acceptance of this argument leads to a belief that win studies underestimate the importance of heredity, while the previous one leads to the opposite conclusion.

In earlier papers I have attempted to rank order the various abilities with respect to the importance of heredity, and suggested the order: Spatial Visualization, Word Fluency, Vocabulary tests, especially if they call for a little more productive answer than choosing from multiple choices, Number Ability and perhaps some types of Reasoning. Perceptual Speed or Clerical Speed and Accuracy also seemed to have a considerable hereditary component. In the Memory tests used so far no effect could be detected of hereditary influence. Tables 2, 3 and 4 summarize the information on which these generalizations were based. For further discussion see Vandenberg (1966a).

Table 2

Value of F, the ratio between fraternal and identical within-pair variances for 6 PMA subtests in four separate twin studies

	F ratios between dizygous and monozygous within-pair variance			
Name of PMA subtest	Blewett	Thurstone	Vandenberg (Michigan)	Vandenberg (Louisville)
Verbal	3.13**	2.81**	2.65**	1.74*
Space	2.04*	4.19**	1.77*	3.51**
Number	1.07	1.52	2.58**	2.26**
Reasoning	2.78**	1.35	1.40	1.10
Word fluency	2.78**	2.47**	2.57**	2.24**
Memory	not used	1.62	1.26	not used

** $p < .01$

* $p < .05$

Table 3

Two Twin Studies of the Differential Abilities Tests

	1961	1965
Verbal Reasoning	2.29**	2.38**
Numerical Ability	1.39	1.37
Abstract Reasoning	1.47	1.23
Space Relations	1.67	2.19**
Mechanical Reasoning	1.36	1.46
Clerical Speed and Accuracy	2.54**	3.25**
Language Use I: Spelling	3.64**	2.58**
Language Use II: Sentences	3.06**	2.00*
	25 DZ / 47 MZ	86 DZ / 109 MZ

** $p < .01$; * $p < .05$

Table 4

F ratios between the within-pair variances of 60 fraternal and 60 identical twins for the scaled scores of 11 subtests of the WAIS

Subtest	F
1. Information	3.88***
2. Comprehension	2.25**
3. Arithmetic	2.78***
4. Similarities	1.81*
5. Digit Span	1.53*
6. Vocabulary	3.14***
7. Digit Symbol	2.06**
8. Picture Completion	1.50
9. Block Design	2.35**
10. Picture Arrangement	1.74*
11. Object Assembly	1.36
Verbal Score	3.38***
Performance Score	3.41***
Total Score	3.47***

*** $p < .001$; ** $p < .01$; * $p < .05$

Several other studies can be added to these. There is, first of all, the study of Wictorin (1952). His results are summarized in Table 5. We find highly significant evidence for an hereditary component in two tests of "general" intelligence. I have not seen these tests so that I cannot tell you whether they are largely

Table 5

F ratios between like-sexed fraternal (DZ) and identical (MZ) within-pair variances for 14 psychological tests, administered to Swedish twins of elementary and high school age (Wictorin 1952)

	Boys	Girls	All Cases
Simplex, a general intelligence test	1.98**	2.84**	2.38**
C-test, a general intelligence test	2.41**	4.35**	3.37**
Verbal Analysis, a verbal comprehension test	1.14	.96	1.12
Form perception, a paper formboard test	1.51*	1.23	1.34*
Picture perception, a perceptual speed test	1.17	1.54*	1.36*
Number perception, a clerical checking test	1.58*	1.91**	1.59**
Number Series, a numerical reasoning test	2.37**	1.70*	2.01**
Number Analysis, a numerical reasoning test	1.61*	1.68*	1.63**
Numerical Classification, a numerical reasoning test	1.47	1.64*	1.57**
Numerical Reasoning, verbal arithmetic problems	2.83**	1.96**	2.18**
Routine simple arithmetic	1.87**	1.51*	1.68**
Memory for 2-digit numbers (Recall)	1.15	1.39	1.24
Memory for 3-digit numbers (Recognition)	.94	1.34	1.17
Paired associates, word-number memory	1.32	1.00	1.16
N_{DZ}	66	75	141
N_{MZ}	66	62	128

** $p < .01$; * $p < .05$

verbal or figural or a mixture of both. We see further evidence for a considerable hereditary component in number ability, and in perceptual speed, and again in memorizing tests. There are some interesting differences between the results for boys and girls, but it would take us too long to pursue this here. In the appendix the intraclass correlations are listed for those who may be interested.

The next table, Table 6, summarizes the findings of Husen (1953), who tested the twins among Swedish conscripts, probably an unselected and therefore as representative a sample as can be found. The five tests he used were: a. following instructions, a verbal comprehension and speed reading test; b. finding synonyms; c. choosing the odd word, two vocabulary tests; d. Raven's progressive matrices, a reasoning test which uses figural material (claims have been made for this test that it measures "general" intelligence), and e. number series, a numerical reasoning test.

Table 6

Ratios between unlike-sexed fraternal (DZ) and identical (MZ) within-pair variances for 5 psychological tests, administered to Swedish twins (Husen 1953)

Nature of the test	F	N_{DZ}	N_{MZ}
Following instructions	2.62**	415	215
Finding synonyms	2.09**	532	269
Choosing the odd one from among 5 words	1.77**	532	269
Raven's Progressive Matrices	1.37*	532	269
Number Series	1.54*	117	54

** $p < .01$; * $p < .05$

The evidence for an hereditary factor is good for the one verbal comprehension and the two vocabulary tests and not as strong, but still significant, for the figural reasoning or general intelligence test and the numerical reasoning test. In Table 7 the results are shown of an analysis Husen made of the school grades of these twins. Note that the highest F value was for the arithmetic grade, but that all values are significant way beyond the one percent level. It is interesting to compare these results with those reported by Nichols (1965) for the NMSC test results.

Table 7

Ratios between unlike-sexed fraternal (DZ) and identical (MZ) within-pair variances for school grades in 4 subject matters of Swedish twins (Husen 1953)

Subject Matter	F	N_{DZ}	N_{MZ}
Arithmetic	3.13**	668	352
History	2.82**	624	332
Handwriting	2.45**	668	352
Reading	2.23**	662	350

** $p < .01$

Table 8 gives F ratios separately for boys and girls for the scores on the following 5 parts of the NMSC qualifying test: English Usage, Word Usage, Social Studies Reading, Mathematics Usage and Natural Science Reading. All values but one are significant beyond the one percent level, and that one is significant at the 5 percent level. Since these test scores are also based on achievement, this is very good confirmation of Husen's findings.

Table 8

F ratios+ between within-pair variances for fraternal (DZ) and identical (MZ) twins on 5 parts of the National Merit Scholarship Qualifying Test (after Nichols 1965)

	Boys	Girls
English Usage	1.23*	2.22**
Word Usage	1.72**	2.56**
Social Studies Reading	1.92**	2.27**
Mathematics Usage	2.22**	1.75**
Natural Science Reading	2.86**	1.54**
N_{DZ}	209	273
N_{MZ}	315	372

** $p < .01$; * $p < .05$

+ These F ratios were estimated from intraclass correlations rather than calculated directly from within pair variances.

Finally I am able to report some results from a recent study of adult Finnish male twin pairs, due to the courtesy of the authors who let me read the manuscript, (Bruun et al. 1966). They administered 8 tests of 5 primary mental abilities. The tests were Verbal Opposites, a vocabulary test; a Word Fluency test; two spatial ability tests: Rotated Squares and Paper Form Board; two number ability tests: Addition and Subtraction, and Find the Longest Number (this one contains a clerical checking factor); and two Memory tests. (See Table 9). There was highly significant evidence for an hereditary component in all the

Table 9

Intraclass correlations and F ratios between fraternal and identical within-pair variances for 8 ability test scores of Finnish male adult twins (Bruun et al. 1966)

		Intraclass Correlation MZ	Intraclass Correlation DZ	$F = \frac{\sigma^2_{wDZ}}{\sigma^2_{wMZ}}$
V,	Verbal opposites	75	51	1.94**
W,	Word fluency	81	54	2.28**
S_1,	Rotated squares	58	33	1.75**
S_2,	Paper form board	60	39	1.69**
N_1,	Addition and subtraction	73	55	1.98**
N_2,	Find the longest number	72	45	1.92**
M_1,	Memory for names	69	35	2.09**
M_2,	Memory II	58	29	1.98**
Number of pairs		157	189	

** $p < .01$

tests. With so many different abilities showing an important hereditary component in several studies, one may ask whether this hereditary component is, perhaps, the same in all tests, with the non-genetic part determining its specific character.

We can get some idea about this by seeing whether the twin who does better than his brother on test 1, also does better on test 2. We can get such information quickly by correlating the twin differences on a number of tests. This was done separately for the identical twins and for the fraternal twins with the 6 subtests of the Primary Mental Abilities battery of Thurstone, and with the 8 subtests of the Differential Aptitude Test.

For the PMA the algebraic average of these correlations was .215 for the identical twins, and .373 for the fraternal ones. For the DAT the figures were .157 and .465. The complete tables are shown in Vandenberg (1966a).

Because the identical twin differences are due to environment plus heredity, it occurred to me that if we could subtract the first set of correlations from the second, we would have left the correlations between the fraternal twin differences on different abilities which are due to heredity. Because such matrices tend to be non-Gramian, and because heredity and environment are not simple additive this cannot be done. Instead I decided to divide one matrix by the other in a generalization of the F test. We use $F = \sigma^2_{wDZ}/\sigma^2_{wMZ}$ or $\sigma^2_{wDZ} - F\sigma^2_{wMZ} = 0$ to determine if the excess within-pair variance in the fraternal twins is statistically significant. We do so by looking up the value of F for degrees of freedom N_{DZ} and N_{MZ} in an appropriate table.

By the same reasoning we may ask whether the characteristic equation $\left| C_{DZ} - \Lambda C_{MZ} \right| = 0$ has one or more significant roots. We can use Bartlett's or Anderson's test to determine this (Bartlett 1950; Anderson 1948).

For the PMA battery of 6 subtests, 4 roots were found to be significant. They were interpreted as similar to, although not identical with, Vocabulary Knowledge, Use of Language (as shown in fluency and reasoning), Spatial Visualization and Number Ability. For details see Vandenberg (1965).

A similar procedure was followed in the Finnish study referred to earlier (Bruun et al. 1966). The results of that analysis are shown in Table 10.

Table 10

Solution of $\left| C_{DZ} - \Lambda C_{MZ} \right| = 0$ for 8 ability test scores of 157 fraternal (DZ) and 189 identical (MZ) adult, male, Finnish twins (Bruun et al. 1966)

V	330*	421	-470	-029	-210	408	-718	-002
W	518	100	080	-877	461	-054	224	-220
S_1	432	414	152	405	284	272	262	-030
S_2	196	281	347	-032	-233	-633	-029	256
N_1	256	-432	-332	008	-476	259	493	601
N_2	-148	-012	652	184	322	-521	020	-217
M_1	493	-189	120	129	-380	-056	137	-666
M_2	261	-582	282	122	367	-117	-322	182
λ, Size of root	3.556	2.256	1.785	1.682	1.246	1.166	1.132	.974
H	.72	.56	.44	.41	.20	.14	.12	-.03

* Decimals omitted

Several tests of the significance of roots have been proposed, f.i. by Bartlett (1950). The test of Bartlett consists of examining the homogeneity of the remaining roots after extraction of k roots. To do so, he uses the distribution ratio of the product of the remaining p-k roots to the arithmetical average of the remaining roots raised to a power equal to their number. The formula is

$$\text{chi square} = -\left\{ n - \frac{1}{6}(2p + 5) - \frac{2}{3}k \right\} \log_e R_{p-k}$$

where $$R_{p-k} = \frac{R}{\lambda_1 \lambda_2 \cdots\cdots \lambda_k} \left[\frac{p-k}{\Sigma \lambda_i - \lambda_1 - \lambda_2 \cdots\cdots\cdots \lambda_k} \right]^{p-k}$$

with degrees of freedom

$$\frac{1}{k}(p-k)(p-k-1)$$

A slightly different test has been proposed by Anderson (1948). It uses as the criterion whether the k the root is significant the following formula

$$\frac{1}{\sqrt{n}}(\Lambda_k - k.n.)$$

which has a distribution close to normal with zero mean and variance 2k for large n; otherwise

$$\frac{1}{\sqrt{n}}(\Lambda_k - k.n) - \sqrt{np}^2$$

is asymptotically normally distributed with zero mean, and variance $2k + 4p^2$

where $$\Lambda_k \doteq (n-1) \sum_{k+1}^{p} \lambda_i$$

and where n is the number of cases, p is the smallest non-zero root, and p is the total number of roots.

These tests are for symmetric matrices and therefore, perhaps, not exactly appropriate for the roots of an asymmetric matrix. The rationale for a test of the significance of the roots of an asymmetric matrix should not be too different however. To be on the conservative side, I have used an n of 100 in the calculations rather than the total number of twin pairs.

Tables 11 and 12 show that both tests indicate that 4 roots are significant. These findings provide partial confirmation of my earlier findings of 4 significant independent hereditary components in ability.

Table 11

Anderson's test for the significance of the kth factor

(taking n = 100)

k	$\sum_{k+1}^{p} \lambda_i$	Λ_k	kn	Λ_k - kn	$\frac{\Lambda_k - kn}{\sqrt{n}}$	σ	CR	p
1	10.241	1024.1	100	924.1	92.41	1.414	65.35	.001
2	7.985	798.5	200	598.5	59.85	2.000	29.92	.001
3	6.200	620.0	300	320.0	32.00	2.449	13.067	.001
4	4.518	451.8	400	51.8	5.18	2.828	1.832	.05
5	3.272	327.2	500	negative	—	—	—	

Table 12

Bartlett's test of the significance of the k + 1th root after extraction of k roots (taking n = 100)

k	λ_i	x^2	df	p
0	---	67.783	42	.005
1	3.556	26.620	15	.025
2	2.256	13.596	6.66	.025
3	1.785	7.927	3	.025
4	1.682	1.503	.75	n.s.

Hereditary factors in personality

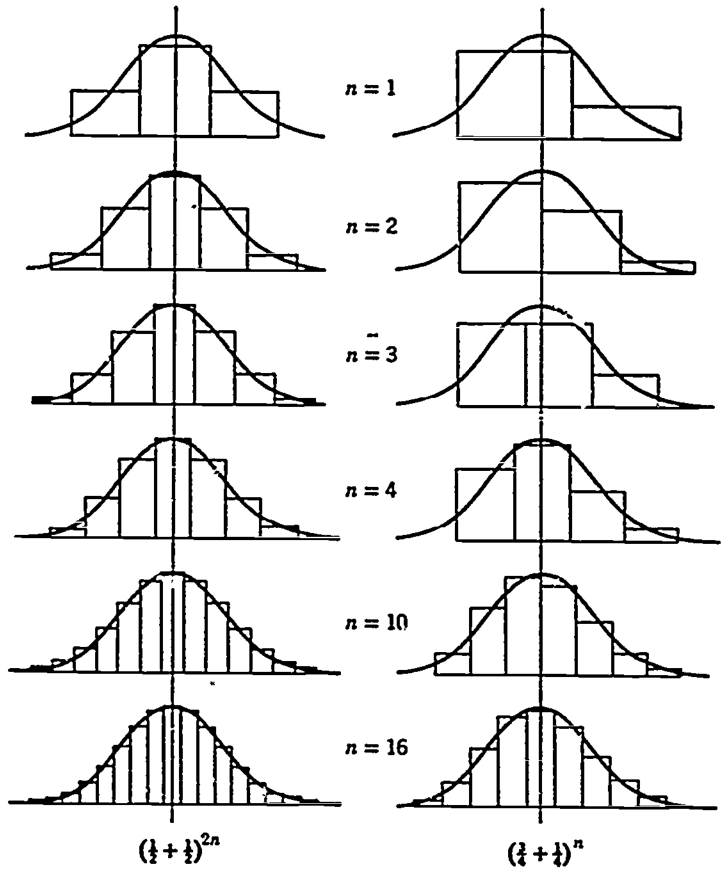
I will have to refer you to a paper in the next volume of Recent Advances in Biological Psychiatry (or to one of our prepublication reports) for a review of hereditary factors in personality (Vandenberg 1966b). There is a table there which summarizes 15 studies. In that paper I concluded that there is most consistent evidence for hereditary determination of a trait variously named sociable, extraverted or its opposite shy, withdrawn, introverted. This may or may not be related to schizophrenia, with the shy person, perhaps, being heterozygous for the schizophrenia gene(s). Possibly two or three loci are involved. That even a few loci can produce an approximation to a smooth distribution is shown by Figure 9. If one allows environment to play some part, there might, of course, be an even better fit to a normal distribution.

Although parental influence probably is a factor in schizophrenia, it may be profitable to study in detail the pedigrees of generally extroverted sociable families with an occasional shy, withdrawn child, to see if such exceptions occur elsewhere in the pedigree in any meaningful pattern.

Other clusters of personality traits for which there was strong and consistent evidence of an hereditary component were: a. dominance, assertion, self-confidence; b. active, vigorous, depression (at the negative end), surgency, energetic conformity and need for achievement; and c. neuroticism, psychasthenia psychoneurotic and psychosomatic complaints.

Figure 9

Gradual approximation to normal curve of phenotypes controlled by n pairs of genes. Left: no dominance Right: complete dominance for all genes (after Lush 1945)



Enumeration of traits for which the evidence was less strong or less consistent would take too long today. I do want to underline the fact, however, that the evidence for a hereditary component in some personality traits is almost as strong as for some abilities.

Discussion of differences between the conclusions of different twin studies, even if they had used similar psychological tests, is complicated by the fact that estimates of heritability may vary; a. because of real differences between the heritability of traits in different populations, b. because the degree to which various methods of measuring hereditary components differ on a number of criteria, c. because of the usual limitations of tests: lack of perfect reliability and validity.

The usual considerations of limited validity and reliability of tests have to be augmented by some special ones: two similar looking tests of, say, vocabulary with equal validity and reliability may still give different estimates of the significance of hereditary components, because we are dealing with differences between twins and not with the scores themselves. Such differences may be unduly affected by differences in format, or by the time of day when the test is administered.

Evidence from inbreeding

Schull & Neel (1965) analyzed the score of 2,111 children on a Japanese version of the Wechsler Intelligence Scale for Children (WISC), constructed by Kodama & Shinagawa (1953). Complete data were available on 1,854 children in the consanguinity groups shown in Table 13.

Table 13

The number of boys and girls in the various categories of consanguinity

	PARENTS ARE			
	unrelated	second cousins	1-1/2 cousins	cousins
Males	538	88	89	249
Females	451	100	102	237
Totals	989	188	191	486

As a first cousin marriage is between a child of one sibling marrying a child of another sibling, children of first cousins have, on the average, 1 out of 16 pairs of genes by common descent. A marriage of first cousins once removed is between a child of one sibling and a grandchild of another sibling. Children of such unions will have on the average 1 out of 32 pairs of genes by common descent. A marriage between second cousins is between a grandchild of one sibling and a grandchild of another sibling. Children from such marriages will on the average have 1 out of 64 pairs of genes by common descent. Genes by common descent, that is obtained from the same ancestor, result in homozygous pairs of genes. The more pairs of genes, or loci, are homozygous, the more inbreeding. Unrelated individuals are assumed to have no genes in common, so children from such unions are regarded as heterozygous for all loci. Children from a first cousin marriage have a coefficient of inbreeding, F equal $1/16$, for those from first cousin once removed marriage $F = 1/32$, and for offspring from second cousins $F = 1/64$.

The consanguinity groups were carefully compared for differences in socioeconomic status and parental age and any differences removed statistically.

The effect of inbreeding was estimated by multivariate linear regression methods, after removing the effects of age and socioeconomic status (SES). The means and standard deviations for age in months and SES, are shown in Table 14. The SES scale used ran from 1 to 20.

Table 14

Means and sigmas for age and socioeconomic status (SES)

Variable	Boys		Girls	
	Mean	SD	Mean	SD
Age	102.91	17.83	102.23	18.10
SES	20.88	5.26	21.06	5.15

Tables 15-17 show the relative effect of inbreeding compared to an increase in age by one month or an increase in socioeconomic status of one point (on a 20 point scale). While the effect of inbreeding is not great, it is quite significant statistically and it can be stated that the effect on the WISC scores was among the clearest and strongest of all the phenomena studied by Schull & Neel. Other items included physical illnesses, several anthropometric and dental variables, and school grades.

Whatever the size of the effect, the fact that inbreeding after correction for socioeconomic status does lead to lower WISC scores, is, perhaps, the most unassailable evidence for hereditary control over intelligence that we have, and it is certainly very suggestive evidence for a multifactorial system, not just one controlled by a small number of loci ; 3 to 8.

Table 15

Comparison of the changes in WISC subtest scores per month of age, per unit of socioeconomic status (SES) and per 10 percent inbreeding (F) (from Schull & Neel 1965)

WISC subtest	Age	SES	F
Information	.0418	.1230	- .950
Comprehension	.0271	.0832	- .742
Arithmetic	.0332	.0844	- .602
Similarities	.0347	.1449	-1.157
Vocabulary	.0480	.1355	-1.155
Picture completion	.0138	.0817	- .656
Picture arrangement	.0264	.0708	-1.073
Block design	.0234	.0834	- .598
Object assembly	.0030	.0717	- .630
Coding	.0264	.0712	- .531
Mazes	.0080	.0260	- .651

Table 16

Effect of inbreeding on intelligence as measured by a Japanese version of the WISC, N = 2,111 (from Schull & Neel 1965)

WISC subtest	Mean for outbred* (offspring of unrelated parents)		Depression of score per 10% increase in F, the inbreeding coefficient	Depression as % of mean for the outbred
	Boys	Girls		
Information	11.62	11.21	-0.9499	8.1 - 8.5
Comprehension	12.39	12.12	-0.7424	6.0 - 6.1
Arithmetic	11.84	12.11	-0.6025	5.0 - 5.1
Similarities	11.40	11.91	-1.1575	9.7 - 10.2
Vocabulary	10.35	9.86	-1.1551	11.2 - 11.7
Picture completion	11.71	10.63	-0.6560	5.6 - 6.2
Picture arrangement	11.54	11.27	-1.0728	9.3 - 9.5
Block design	11.24	10.99	-0.5975	5.3 - 5.4
Object assmebly	10.83	9.94	-0.6298	5.8 - 6.3
Coding	11.54	12.27	-0.5314	4.3 - 4.6
Mazes	12.30	12.09	-0.6526	5.3 - 5.4

* Estimated for a child of 120 months of age, a socioeconomic status of 20, and after correcting for the confounding effect of socioeconomic status.

Table 17

Changes in IQ per month of age, per unit of socioeconomic score, and per percent inbreeding (F) for all consanguinity classes

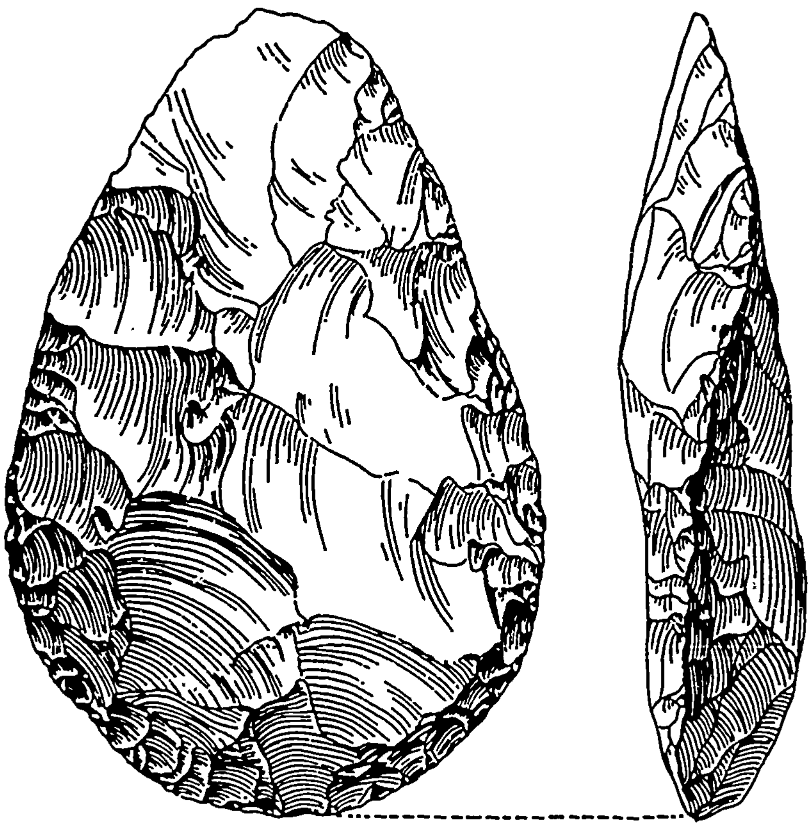
	IQ	Age	Socioeconomic status	F
For Males	Verbal	0.1687	0.6671	-0.3159
	Performance	0.0921	0.4514	-0.2444
For Females	Verbal	0.2020	0.4679	-0.5927
	Performance	0.0936	0.3036	-0.4280
Both Sexes	Verbal	0.1852	0.5740	-0.4418
	Performance	0.0930	0.3827	-0.3289

Comparative and evolutionary evidence

If abilities are partly controlled by genes then evolutionary processes must have been responsible for their present distribution. Do we have any information from human paleontology and prehistory which is helpful in understanding the origin of the basic dimensions of human abilities? The essentials of man's evolution are thought to have been: Walking erect, thus freeing the hands for increased manipulation and tool use; the adoption of permanent tools and their gradual improvement through specialized manufacturing; the increased effectiveness of group action through speech; and above all the cultural transmission of information, as speech; and above all the cultural transmission of information, as speech evolved into language, writing and finally schools, universities and libraries.

Leakey (1961) discusses the methods for producing certain types of stone tools. He learned how certain types of flakes could be split from a piece of flint by aiming a blow with a bone in a certain manner. Prehistoric man learned to do so and gradually improved his skill, which would have required a certain amount of spatial visualization and mechanical ability, as well as training in it. Figure 10 copied from Leakey (1961) gives an example of the fine work this could produce. This is roughly dated as from before the third glaciation

Figure 10



Stone Tool from Acheulian Period

(from Leakey 1961)

Recent field studies of primates by Jane Goodall (1965), Devore (1965), Schaller (1964) and others have shown that the gap between man and his nearest kin, though they be countless generations apart, is not as great as we once thought.

Do we have any evidence from comparative studies of other animals which bears on the evolutions of primate abilities? Time does not permit summarizing some of the suggestions of tool using, leadership, sacrifice for the group, etc. which have been made. I would rather specualte about the emergence of the abilities we have been dealing with. I am not competent to deal with this topic adequately in animals, but this will not stop me from saying something about it anyway, as you may expect by now.

The rudiments of number concepts may lie in the awareness of numerosity and patterning. Surely the territoriality so artistically described by Ardrey (1966) implies some awareness of memory of spatial arrangemenst. Many studies have demonstrated memory and learning in a variety of species. In fact there can be no doubt that the basic arrangement for storage must have been worked out very long ago, perhaps right along with the genetic mechanisms themselves, if current ideas about biochemical factors in learning are accurate.

Verbal ability is, of course, uniquely human, and with it came a proliferation of problem solving skills and extremely well-practiced and overlearned "subroutines" which permit the construction of much more complicated abilities, perhaps to some degree different for every person as unique combinations are worked out in his personal life history. In fact, I believe so strongly in the uniqueness of the individual and his intelligence, that I am now willing to second, with some modification, a definition of intelligence proposed by a Russian. I find it encouraging that we have come so close together from rather different points-of-view.

I have taken a definition offered at the XVIIIth International Congress of Psychology by Novoselova (1966) and have made only minor changes, and added only some sentences at the end dealing with hereditary variations.

It goes like this:"Intelligence is a multifacetted, progressively evolving, adaptive activity which undergoes constant reörganization leading to qualitative changes, during the lifetime of the individual. It is developed in unity with the capacity to perceive dynamic processes in the person's sphere of activity, and it is based on the use by each person of his individual experiences, be they original or imitation, as well as of social tradition, which to a large extent is laid down in a variety of symbolic forms (what anthropologists call artifacts). It is based on the common human sharing in abilities acquired during the evolution from prehuman forms." When the "normal" genetic endowment is disturbed by abnormal genes, or abnormal chromosome number, there may be interference in development which will result in serious retardation. The hereditary component in the normal variation in intelligence is probably determined by a multiplicity of genes having small cumulative effects. The importance of heredity will vary according to the aspect of intelligence under study and the age and socioeultural environment of the subjects.

The Nurture of Intelligence

Do the genes which we have acquired in the long evolution of human abilities need special conditions in order that these abilities may come to fruition in a particular child? We have some suggestive evidence on this point, although not in as much detail as we need for a tight argument. The existence of feral children is almost certainly a myth, but clinical observations on children without adequate mothering are now backed up by the studies of Harlow (1962), or Scott & Fuller (1965) and others, which show that a minimum of social interaction is necessary for normal development in higher mammals, such as monkeys and dogs. Recent work by Krech, Rosenzweig & Bennett (1960) shows that differences in the amount of stimulation leads to differences in brain chemistry mediating the differences in ability. I have not had an opportunity to digest and use Wolff's monograph (1966), on the behavior of neonates.

That the lack of early stimulation has depressing effect on mental development is pretty generally accepted. To what extent an increase in early stimulation has the effect of raising the intellectual level has still to be demonstrated, although the differences in ability between socioeconomic classes are often attributed to this, in part or in their entirety. To dramatize the distinction to be made we need to know: whether early experience can do something other than stunting; and whether it would act in a manner similar to a hothouse, forcing an early bloom (as in an Easter lily), but a bloom which is no different than it would have been a little later anyway; or whether it would act more like fertilizer producing bigger and better yields. Once we have answers to these questions we could try to persuade parents to let us stimulate one twin early and often, while the other is left to his own devices, so that we could stretch the heredity-environment experiment to its limit.

That stimulation does not have an all or none character, but is graduated, seems well-demonstrated by studies of lower class whites and Negroes who moved or did not, to more favorable environments, although the possibility of selective migration of the more capable cannot be ruled out. Since environmental factors seem of importance, it may even be possible to draw a map of the geographical distribution of ability after controlling statistically for some of the more gross economic factors. Such a map would suggest more detailed studies to see whether, in addition to environmental factors, there might be geographic differences in ability which somehow have coalesced into clines or regions of similar ability. Data from the National Merit Scholarship Corporation and from project TALENT can be used to produce such a map. The unmistakable correlation between the number of Nobel prize winners and the economic and cultural development of the country of origin of these scientists is a strong argument for the environmental contribution to high ability, since countries differing in scientific achievement frequently have similar genetic backgrounds.

Studies of the influence of college on students will give more detailed information on the question for how long a period stimulation can influence development. Nichols (1966) has reviewed studies performed at NMSC by himself, Holland and Astin in which little effect of college was demonstrable in the aggregate on the talented students in the Merit program as far as their career plans, intellectual achievement or personality was concerned. The recent report by Coleman et al. (1966) on Equality of Educational Opportunity in the U.S. concludes that, of the total variability in intellectual ability and in achievement, only between 10 and 20 percent was associated with differences between schools, while most of the variance was within schools. Differences between schools in the test scores were as large for the first grade as for the twelfth grade, and most differences between schools disappeared when student background factors were controlled.

These findings would suggest that in the U.S. the major source of differences in ability is no longer the quality of schooling, but rather the quality of preschool experience, as well as innate differences. Of course, this does not mean that full equality in the former has been reached, since even 10 percent indicates sizeable differences, but it does indicate the relative importance of the latter factors.

A similar conclusion seems to have been reached in Sweden (Svenson 1962). Ninety-four hundred students from different types of schools in Stockholm were compared. No relation was found between test scores for general ability, reading, writing, mathematics, English, German, history, or chemistry and whether or not the students had been put in the college preparatory classes, rather than general classes in the 5th, 7th or 9th grade. A slight tendency towards superior performances of students who had been put in differentiated classes early observed in grades 6 and 7 was not found in grades 8 and 9.

An English study suggests that ability and social class may interact when the effect of different curricula are studied. Dockrell (1966) tested, in a single community in England, children whose fathers were middle class or lower class, and who went to grammar school or a technical school. He concluded from the patterning of scores on the various tests that children from middle class homes have reached a level of development in all abilities, which makes it unimportant (at least from the point-of-view of their mental development) what type of secondary school they attend. Children of lower class homes do not have the same level of development especially in verbal areas, and for them the type of school does make a difference.

I mentioned in the beginning of the paper that we need to know more about the influence of education on the various specific abilities. It seems fair to say that we have only some indications of what the outcome of such would be. A few quite promising studies of the effect of training in late adolescence on spatial test scores are suggestive of the kind of data we should have.

Myers (1958) found that U.S. Naval cadets with previous training in Mechanical drawing had no better spatial relations test scores than those who did not.

Ranucci (1952) found that high school solid geometry did not have an effect on spatial relations test scores. Blade & Watson (1955) reported three studies in which a college engineering course improved spatial test scores significantly. However, engineering students may already have a certain facility on spatial tests. A more crucial test would be to use unselected high school students for a study of the effect of training. Various influences may very well differ in importance between occupations and types of college specializations. This is suggested by a study of Hilton & Myers (1966) in which different background factors predicted, at widely varying levels, the performance of 12th graders on 5 different criteria. Figure 11 summarizes their findings.

Closer to home, the influence of parental treatment has been investigated by Bayley & Schaefer (1964), and by Kagan & Moss (1962). Their findings may be summarized as follows: Kagan & Moss analyzed data from the Fels Institute for the relation between maternal behavior and characteristics of their child's behavior and found many significant correlations. They also report many significant correlations between the child's behavior and his adult behavior. Especially striking was the consistency between variables relating to achievement in the child and striving for recognition when adult.

Figure 11

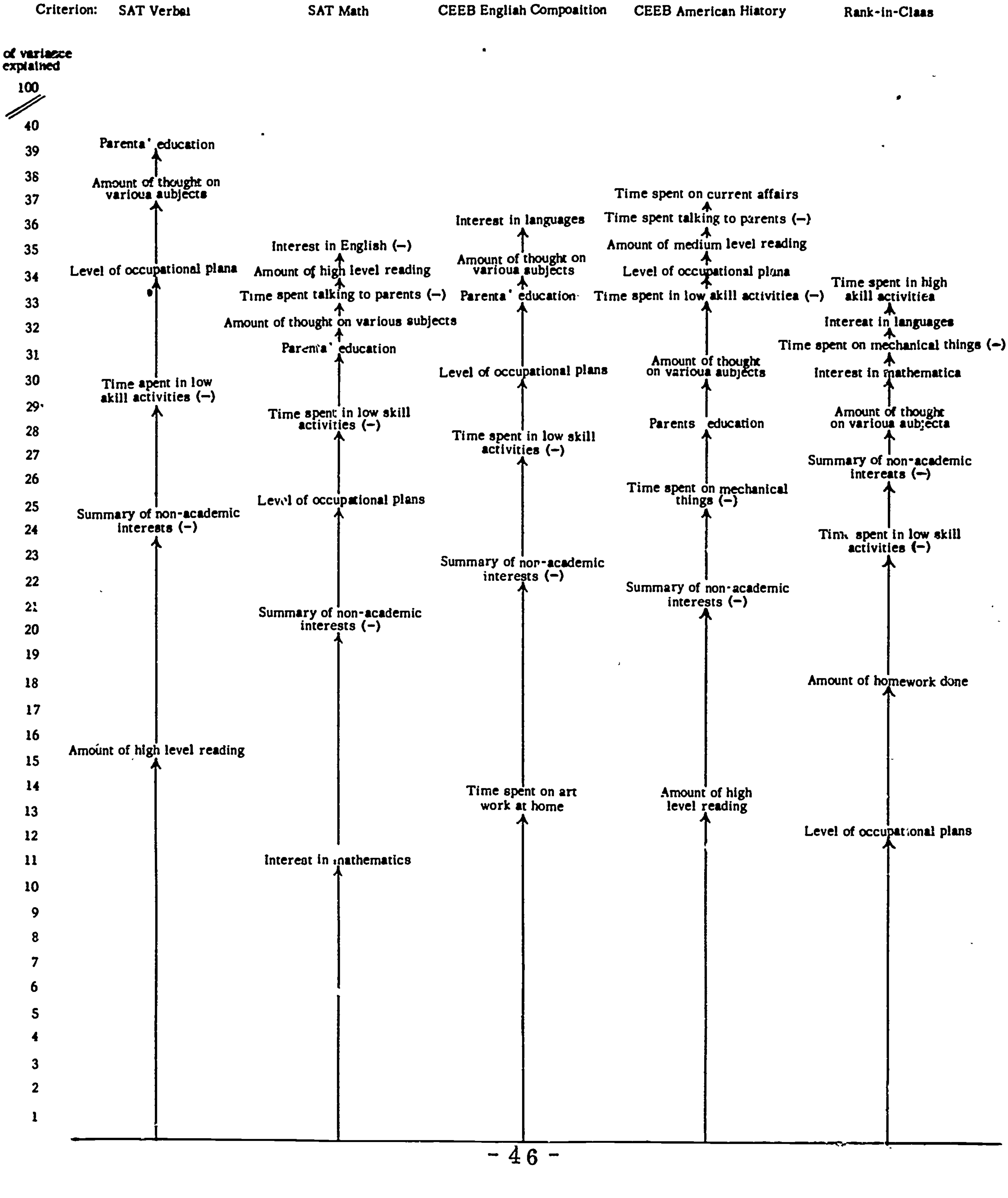
BACKGROUND AND EXPERIENCE QUESTIONNAIRE

(Hilton & Myers 1966)

Stepwise multiple regression prediction of 12th grade test scores and rank-in-class.

Sample: All academic boys in 12th grade in Spring, 1963, N = 1206

Predictors: BEQ Scores only



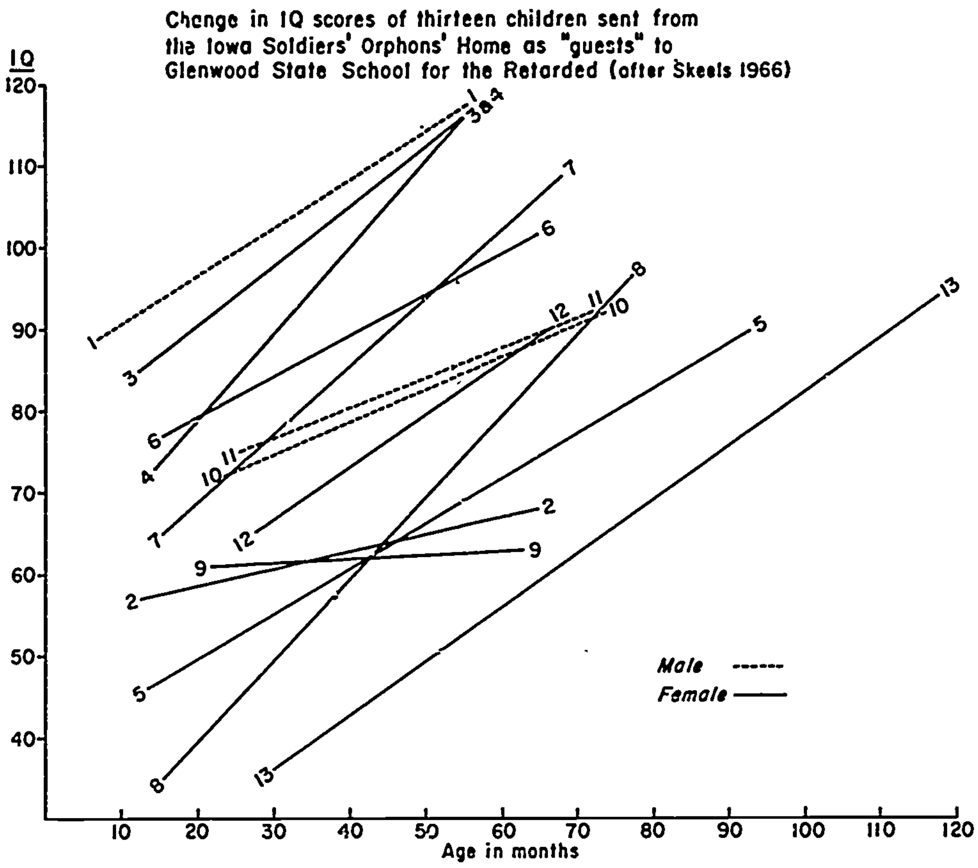
Bayley & Schaefer (1964) similarily found many significant correlations between maternal behavior and the performance of children from the Berkeley Growth Study on intelligence tests during the first year (4 age levels), during the period from 13 to 56 months of age (4 age levels) and between 5 and 18 years of age (5 age levels). They found an interesting sex difference in the patterning of these correlations. Various punitive or strict types of behavior by the mother tended to produce positive correlations with IQ during the first year of life for boys, but not for girls; but negative relations with IQ in the two later periods for boys, but for girls only during the 13 to 54 months period. In fact for girls the correlations between maternal behaviors and intelligence in the 5-18 year period were generally low, while for boys such correlations were negative, except for "positive evaluation" and "equalitarianism" on the part of the mother. Relations between maternal and child behavior, other than intelligence, were reported in Schaefer & Bayley (1963).

The most dramatic claim for the positive effect of early stimulation would seem possible on the strength of a recent monograph by Skeels (1966). Twenty-five orphanage children, born out of wedlock or taken from their parents for severe neglect, formed the subjects of a most interesting study by Skeels and his associates. More than 30 years ago Skeels persuaded authorities to move 13 of these children from the orphanage to an institution for the mentally retarded. The results sound paradoxical: these children had dramatic increases in IQ when compared with 12 children who stayed in the orphanage. The explanation lies in the fact that the orphanage provided little individual attention, while the children who were sent to the institute for (adult) mentally retarded were assigned one or two to a ward where they were fussed over by the inmates, attendants and nurses. Figures 12 and 13 show the changes in IQ for the two groups.

Even when one allows for the fact that intelligence tests administered during the first year of life are poor predictors of later IQ, the consistent increase in the "experimental" group is in marked contrast with the absence of marked increases in the "control" group.

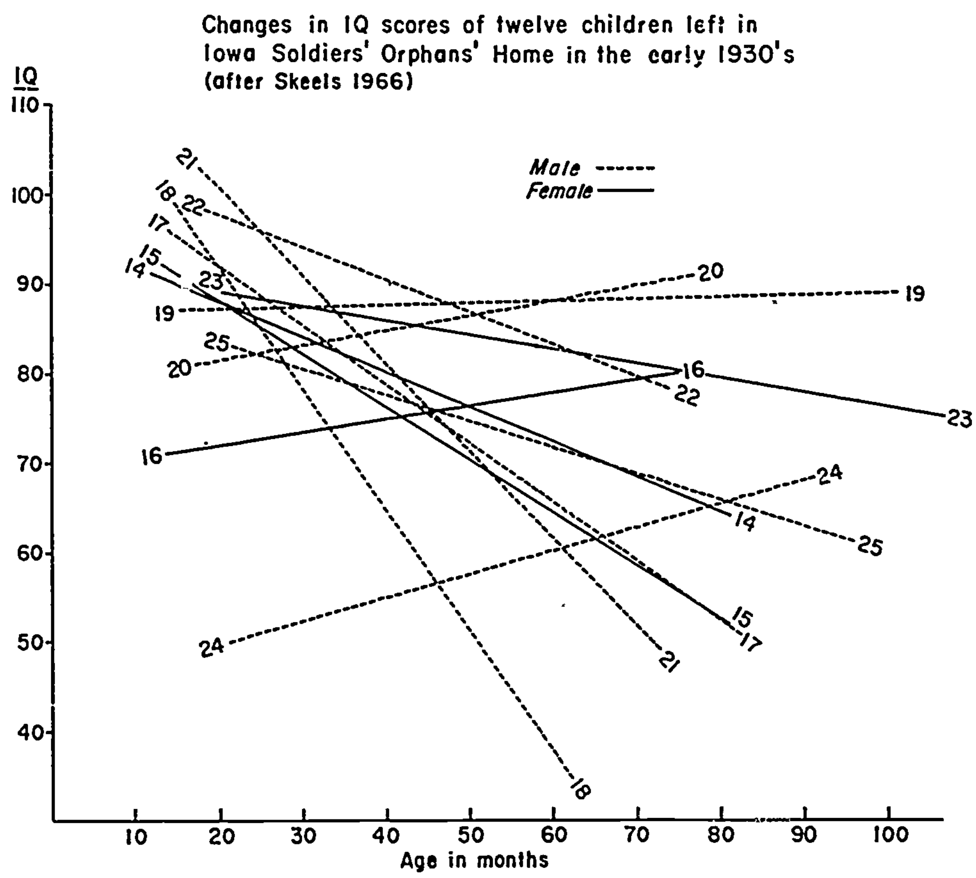
Even birth order, at first sight such a simple fact, turns out to be complex enough to need further study, though some effects are general. Sampson (1965) has

Figure 12



reviewed the effect of ordinal position recently. It may be summarized as follows: first-born more likely to attain intellectual eminence, especially in sciences, less likely to express aggressive feelings overtly, more likely to seek company of others when anxious, yet be rated less sociable, outgoing, empathic, sympathetic, less self-esteem, experience shift in centrality of his family role, more likely to experience conflict over dependence versus independence, had no model preceding him.

Figure 13



Altus (1966) gave further evidence on the increased frequency of eminence and high educational attainment in first-born children, reviewing, in part, data collected by Nichols at the National Merit Scholarship Corporation, which show that a higher percentage of NMSC finalists are first-born children. Even month of birth may also be of importance. Berglund (1966) found no relation between intelligence and season of birth in 708 normal children, slight difference for 237 children with $X^2 = 4.64$ p between .10 and .05 [Medians- Dec.-Mar. 77.6; April-July 78.5 and Aug.-Nov. 79.8] Pintner & Forlano (1933) reported a lower mean IQ for children born between January and March. Orme (1962, 1963) found among 188 retarded adults the highest IQ's for those born in summer and the lowest IQ for those born in the winter. Davies (1964) did not find a relation for 300 normal men with an unusually wide age range.

We need much more detailed information on sex differences and to what degree each of them is culturally and genetically determined, especially since sex linkage is always a possibility.

Ideas about national and racial differences are probably largely based on incorrect stereotypes, but a residue may be due to differences in the level of educational opportunities. Even when the education may be regarded as of equal level there may be differences in the system of education such as the rather free choice of courses in the U.S. versus the more rigid curricula in Europe, and finally there may be differences in patterns of achievements due to national traditions and different value systems for various skills.

Modern technological innovations in teaching by machines and by TV may bring new insights into the acquisition of abilities, as will the newer theoretical ideas inspired by Montessori, Piaget, and others.

Striking a balance

In the first part of the paper evidence was presented for hereditary components in abilities and personality, in the second part the evidence from Skeels, from the longitudinal studies at Berkeley and at the Fels Institute, and from animal work, shows the importance of environment, while the studies of the effect of instruction at the elementary, secondary and college level did not indicate a major influence. Where does this leave us now?

It seems so far, as if the early environment is more critical than the later. And we still do not know if enrichment of the early environment will do as much good, as restriction and deprivation can do harm.

If stimulation can permanently enhance performance then we might effect some type of multiplicative model to hold for abilities, i.e.

$$\text{Ability} = \left[C_1 \times \text{genetic anlage}\right] \times \left[C_2 \times \text{environmental stimulation.}\right]$$

To what extent such a model holds to estimate the specific values of the coefficient C_1 and C_2 for a particular ability can only be determined by co-twin control studies.

Suggestions for research

I want to make a plea for longitudinal co-twin studies in special schools and summer camps. Such an enterprise would furnish information which cannot be obtained in any other way. The other suggestion I have is for the inclusion of well qualified psychologists in cooperative studies of rare genetic anomalies and racial isolates.

Thoughts about the human condition

If we believe Leakey (1961) we may not have changed drastically in over half a million years, other than that we have vastly improved our technical means. It is disheartening to remember that the present great military powers do not exceed Hadrian's, Alexander's or Tamerlane's geographical reach. The increase in man's technical ability has not been accompanied with an equal increase in moral and spiritual development.

I would like to end with a poem by that great misanthrope and pessimist Robinson Jeffers. It is called Original Sin.*

The man-brained and man-handed ground-ape, physically
The most replusive of all hot-blooded animals
Up to that time of the world: they had dug a pitfall
And caught a mammoth, but how could their sticks and stones
Reach the life in that hide? They danced around the pit, shrieking
With ape excitement, flinging sharp flints in vain, and the stench of their bodies
Stained the white air of dawn; but presently one of them
Remembered the yellow dancer, wood-eating fire
That guards the cave-mouth: he ran and fetched him, and others
Gathered sticks at the wood's edge; they made a blaze
And pushed it into the pit, and they fed it high, around the mired sides

Of their huge prey. They watched the long hairy trunk
Waver over the stifle-trumpeting pain,
And they were happy.

Meanwhile the intense color and nobility of sunrise,
Rose and gold and amber, flowed up the sky. Wet rocks were shining, a little wind
Stirred the leaves of the forest and the marsh flag-flowers; the soft valley between
the low hills
Became as beautiful as the sky; while in its midst, hour after hour, the happy hunters
Roasted their living meat slowly to death.

These are the people.
This is the human dawn. As for me, I would rather
Be a worm in a wild apple than a son of man.
But we are what we are, and we might remember
Not to hate any person, for all are vicious;
And not be astonished at any evil, all are deserved;
And not fear death; it is the only way to be cleansed.

Yet that same species invented love, patriotic self-sacrifice, philosophies, religions, arts and sciences. Writers of science fiction have speculated that we need our agression if we are to last, perhaps even in other locations in the universe.

* From "Selected Poems" by Robinson Jeffers, Vintage Books, a division of Random House, the publisher who granted permission for my copying. Copyright Donnan Jeffers and Garth Jeffers.

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Appendix

Intraclass correlations for identical and like-sexed fraternal twins aged 9 to 15 years on 14 psychological tests*

	Boys		Girls		All Cases	
	MZ	DZ	MZ	DZ	MZ	DZ
Simplex, a general intelligence test	79	61	91	76	85	70
C-test, a general intelligence test	86	74	92	72	91	73
Verbal Analysis, a verbal comprehension test	64	55	62	59	63	57
Form perception, a paper formboard test	66	41	65	63	65	53
Picture perception, a perceptual speed test	53	64	72	60	64	61
Number perception, a clerical checking test	83	66	83	70	83	69
Number Series, a numerical reasoning test	78	40	74	55	74	49
Number Analysis, a numerical reasoning test	65	53	74	60	69	57
Numerical Classification, a numerical reasoning test	67	44	74	61	70	58
Numerical Reasoning, verbal arithmetic problems	93	72	83	74	87	73
Routine simple arithmetic	83	75	80	70	81	74
Memory for 2-digit numbers (Recall)	60	64	67	52	62	58
Memory for 3-digit numbers (Recognition)	44	50	54	38	49	45
Paired associates word-number memory	35	47	47	56	43	53
N_{DZ}	66		75		141	
N_{MZ}	66		62		128	

* Decimals omitted